INVESTIGATION OF COATED SANDS AND PEAT FOR USE IN GOLF COURSE PUTTING GREEN CONSTRUCTION

By

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Sand is used for putting green root zones because it permits rapid drainage, good aeration, and resists compaction. However, sand generally has low cation, anion, and moisture retention. Laboratory, glasshouse, and field studies were conducted to determine whether coated sands and peat would improve the poor physical and chemical properties associated with sand-based putting greens and improve bermudagrass (*Cynodon dactylon* L. x *C. transvaalensis* Burtt Davy) growth and quality. Treatments included uncoated sand, naturally-coated sand collected from central Florida, and artificially-coated sand (resin/clay), all with and without added sphagnum peat (150 ml peat L^{-1} sand). While sand type and peat did not influence saturated hydraulic conductivity, peat increased moisture retention, and at low soil moisture potentials artificially-coated sand had a greater water content than uncoated and naturally-coated

sand. In addition, coating and peat increased clipping production, water use efficiency, and potassium (K) uptake. Furthermore, naturally- and artificially-coated sand improved K retention. While naturally-coated sand retained more phosphorus (P) than uncoated and artificially-coated sand, greater P uptake was observed in bermudagrass grown only in artificially-coated sand. In a second glasshouse study it was shown that the maximum effect of many parameters was obtained in mixes containing < 33% artificially-coated sand. Using information obtained from the glasshouse studies to design treatments, two studies were conducted to validate glasshouse findings. Treatments used in the field were uncoated sand; uncoated sand with peat (100 ml peat L^{-1} sand); naturally-coated sand with peat; and artificially-coated sand/uncoated sand mix (25%/75%) with peat. In both studies, bermudagrass coverage was fastest for artificially-coated sand + peat and slowest for uncoated sand without peat. Artificially-coated and the naturally-coated sand, both with peat, usually contained higher levels of moisture. Greater quantities of P and K uptake were generally observed in the artificially-coated sand root zone. These studies suggest that while the main benefit of peat was increased moisture retention, coated sands can provide both this benefit and varying degrees of P and K retention and uptake without decreasing percolation rate.

CHAPTER 1
INTRODUCTION

The primary and most influential component of a United States Golf Association (USGA) constructed green is the root-zone mixture. USGA root-zones mixes are composed primarily of medium-coarse sized sand. The use of sand allows for rapid drainage, good aeration, and resistance to compaction (USGA Green Section Staff, 1993). Most sands, however, have low cation and anion exchange capacity (CEC/AEC), and low water holding capacities. Frequent fertilization and irrigation are required to maintain adequate fertility and moisture levels in the root-zone mix (Li et al., 2000).

In order to improve nutrient and moisture retention in the root-zone mix, various organic and inorganic amendments have been used with some success (Carrow, 1993). Peat moss is an organic amendment commonly mixed with sand in an attempt to improve moisture retention (Beard, 1982). Porous ceramics, diatomaceous earths, and zeolites are examples of inorganic amendments marketed for use in USGA putting greens (Bigelow et al., 2000). These organic and inorganic amendments, however, may decompose or lose their structural integrity, resulting in a gradual change in chemical and physical properties associated with poor putting green performance and turfgrass quality. Because the long term stability and effectiveness of inorganic amendments are uncertain, peat moss is the only amendment recommended for use in greens constructed by the USGA (USGA Green Section Staff, 1993).

Since quartz sand is the primary component of the root-zone mixture, a logical approach to improving putting green performance may be to explore the use of different sand types in USGA putting green construction. In Florida, naturally occurring sands include uncoated or "clean" sand as well as coated (or slightly coated) sand. Coated sands commonly have a reddish-brown hue, due to oxidized Fe and Al in the clay-sized fraction of the coatings. Uncoated sands are light gray or colorless and do not have clay-sized coatings (Harris et al., 1996). Uncoated sands are almost inert, exhibiting few if any reactive chemical properties. Coated sands may, however, improve cation, anion, and water retention due to the presence of Fe/Al oxides and kaolinitic clay (1:1 lattice structure) on the sand grain surfaces. The presence of iron oxides appears to "cement" aluminosilicate clays, such as kaolinite, as coatings on sand grain surfaces (Ryan and Gschwend, 1992).

Unfortunately, coated sands are often found in a particle-size range too fine for use in USGA putting greens and are commonly too remotely located to transport economically. Therefore, in most cases, the less chemically active uncoated sands are used in the construction of USGA greens. The limited availability and use of naturally-coated sands has resulted in the development of an artificially-coated sand that is readily available and of acceptable particle size distribution.

An artificially-coated sand was developed to increase ion exchange and moisture retention without adversely impacting putting green performance. Components of the artificially-coated sand include medium to coarse uncoated sand, 2:1 lattice structure clay (emathlite), and a polyester resin which cements the clay to the uncoated sand. An

artificially-coated sand may permit the use of a coated sand type when a naturally-coated sand with proper particle sizes is unavailable.

Previous research on improving physical and chemical properties of sand based putting greens has focused primarily on the use of inorganic amendments. Less research has focused on the potential benefits that may exist when alternative sand types are used in the construction of sand-based putting greens. Brown et al. (2000) reported increased P uptake and reduced P leaching from bermudagrass established and maintained in lysimeters constructed according to USGA specifications using a naturally-coated sand. The impact of coated sands on physical properties and the movement of other highly mobile plant essential nutrients, including a comparison between naturally- and artificially-coated sands, has yet to be determined. Therefore, a series of experiments was developed to investigate potential benefits associated with coated sands.

The short-term objectives of the glasshouse study were to determine the impact of uncoated and naturally- and artificially-coated sand and peat during establishment on 1) saturated hydraulic conductivity (K_{sat}); 2) water use efficiency (WUE); 3) bermudagrass coverage; 4) clipping yield; and 5) moisture and nutrient retention and uptake by 'Tifdwarf' bermudagrass.

The long-term objectives of the glasshouse study were to determine the impact of uncoated and naturally- and artificially-coated sand and peat on 1) WUE; 2) clipping yield; 3) number of days until wilt; and 4) nutrient retention and uptake by 'Tifdwarf' bermudagrass in consecutive years following establishment.

The objective of the artificially-coated sand rate glasshouse studies was to determine the optimum rate at which artificially-coated sand should be incorporated in a USGA root-zone in order to attain desired effects.

The best performing treatments from the glasshouse studies were chosen for use in the field. The objectives of the field study were to determine the impact of uncoated and naturally- and artificially-coated sand during establishment and maintenance conditions on 1) K_{sat}; 2) moisture retention; 3) bermudagrass coverage; 4) clipping yield; and 5) P and K retention and uptake by 'Tifdwarf' bermudagrass.

CHAPTER 2
REVIEW OF LITERATURE

Coated Sand

In Florida, naturally occurring sands include uncoated sand as well as coated (or slightly coated) sand (Harris et al., 1996). Coated sands generally have a reddish-brown hue, due to oxidized Fe and Al in the clay-sized fraction of the coatings. Uncoated sands are light gray or colorless and do not have clay-sized coatings. Uncoated sands are almost inert, exhibiting few if any reactive chemical properties. In contrast, coated sands may, improve cation (K), anion (P), and water retention due to the presence of Fe/Al oxides and kaolinitic clay (1:1 lattice structure) on the sand grain surfaces. Goethite (iron oxide) appears to "cement" aluminosilicate clays, such as kaolinite, as coatings on sand grain surfaces (Ryan and Gschwend, 1992).

Little research related to coated sand use in turfgrass systems has been conducted. Furthermore, coated sand research has been limited to short-term glasshouse studies. Brown et al. (2000) conducted a glasshouse lysimeter study in order to investigate the influence of uncoated sand, coated sand, and peat on P retention, P uptake, and P leaching using three P sources under two growing conditions (grow-in and established turf). During grow-in, coated sand increased turfgrass establishment rate, clipping yield, P uptake, and soil P. In addition, peat decreased grow-in time for both uncoated sand and coated sand. In the established study peat increased clipping yield from uncoated and

coated sands, and coated sand had greater extractable soil P than uncoated sand. In the established study, however, there was no difference in P uptake. It should be noted that these two studies were not conducted consecutively in the same set of lysimeters; thus the potential for coated sand and peat to function in the same capacity with time remains inconclusive.

Additional work related to coated sands has predominately focused on environmental issues such as heavy metals, hydrophobic organic compounds (HOCs), and clay colloid release. While not conducted on turfgrass, many of the soil chemistry topics addressed, such as chemisorption and CEC, are applicable to turfgrass systems.

Stahl and James (1991) conducted laboratory studies to determine the effect of pH on CEC of goethite and hematite coated sand and the amount and exchangeability of Zn retained on goethite and hematite precipitated as coatings on a sand matrix. The systems were conducted as model systems to simulate Fe-oxide coatings in a soil. It was determined that at pH < 4, the CEC of hematite coated sand was less than that of uncoated sand while, for goethite coated sand, the CEC was greater than for uncoated sand. The CEC of goethite coated sand reached a maximum of 0.14 $cmol_c\ kg^{-1}$ at pH 5.0 with hematite coated sand reaching a maximum of 0.17 $cmol_c\ kg^{-1}$ at pH 7.4. The CEC for uncoated sand was 0.044 ± 0.012 $cmol_c\ kg^{-1}$. Both goethite and hematite coatings increased sorption of Zn in nonexchangeable forms at pHs > 6. The authors concluded that the reductive dissolution of Fe oxides could make nonexchangeable Zn plant available.

Ryan and Gschwend (1994) compared the influence of dissolution of iron oxides and alteration of electrostatic interactions on the mobilization of colloids in a clay- and iron oxide-coated sand because of concern over cases of colloid-facilitated transport of low solubility contaminants. Clay colloid release and iron oxyhydroxide dissolution were measured under conditions in which the sediment was flushed with solutions of varying ionic strength, pH, and reductant and surfactant concentrations. Groundwater produced a relatively high mean clay release rate, but Fe release rate was low. In addition, clay release rates were positively correlated with the detachment energy and unrelated to Fe release rates. Finally, a decrease in ionic strength did not increase clay release rate.

Holmen and Gschwend (1997) investigated the sorption rates of hydrophobic organic compounds in iron oxide- and aluminosilicate clay-coated aquifer sands. They suggested that OM-rich iron oxyhydroxide and aluminosilicate clay coatings, located at the exterior of sand grains, are the principal HOC sorption media. It was observed, however, in column studies that such OM is not accessible to HOCs diffusing into the intact sand coatings. Furthermore, they suggest that tumbling action, such as those encountered in batch test procedures, may serve to detach sand grain coatings.

Peat

Peat is a term used to describe partially decomposed plant material that forms in bogs under cool and moist conditions. Peat is the most popular organic amendment used to improve characteristics of putting green soil mixes (McCarty, 2001). Commercial peats vary considerably in pH, and water and organic matter contents because they are derived from different plant materials, decomposing under different environmental

conditions, (Dyal, 1960; Bethke 1988). Peats are broadly classified into moss peat, reed-sedge peat, and peat humus (Lucas et al., 1965). Peats used to modify sands should be high in organic content and low in ash content. Some benefits of peat include increased moisture holding capacity, source of slow-release plant nutrients, and increased availability of certain elements such as Fe and N (Lucas et al. 1965).

Peats are normally used at rates of 5 to 20% by volume in golf course greens mix. Brown and Duble (1975) reported that an optimum mixture contained 85% sand, 5% clay, and 10% moss peat, on a volume basis. Taylor and Blake (1979) reported that at least 87% sand by weight was required to provide effective modification for turfgrass growth while also assuring an infiltration rate of at least 2.3 cm h^{-1}. Zimmerman (1969), investigating various coarse sand-soil-peat mixtures, determined that increasing peat from 10 to 20% by volume at the expense of soil decreased pH, and increased CEC and N. Horn (1970) reported that peat increased capillary porosity and available water, but speculated that most peat is subject to oxidation within one year.

Peat can have an influential role during establishment. Nus et al. (1987) observed an enhancement in 'Pencross' creeping bentgrass establishment by peat because of increased moisture retention. Waltz and McCarty (2000) also observed that bentgrass established three months sooner in sand containing 15% by volume sphagnum peat relative to straight sand and mixes containing 15% inorganic soil amendments. Bigelow et al. (2000) attributed an increase in bentgrass establishment in medium sand amended with 10% sphagnum peat by volume to greater water retention and to a lesser degree increased nutrient retention relative to unamended sand.

Potassium

Potassium (K) is second to nitrogen (N) in the amounts accumulated by turfgrass plants, excluding C, H, and O. Potassium has been determined to be an essential element in numerous plant functions, such as photosynthesis, carbohydrate and protein formation, water relationships, and enzymatic activity (McCarty, 2001). Jones (1980) suggested a sufficiency range of 10.0 to 25.0 g kg^{-1} for turfgrass. Bermudagrass tissue K typically ranges from 10 to 30 g kg^{-1} (Sartain,1999). A growth response to K application can be obtained when tissue K level is below 13 g kg^{-1} (Snyder and Cisar, 2000). Sartain (2002) reported 30 mg K kg^{-1} Mehlich I extractable soil K may be adequate for optimum growth.

Although K is found in high concentrations in turfgrass, its importance during establishment appears minimal, especially for cool-season grasses. However, warm-season turfgrasses that are vegetatively propagated from plant material with little root structure may benefit during the early stages of establishment from elevated soil K levels because of direct K contact and less diffusion and mass flow distance. Juska (1959) found a positive response to K applications during the establishment of 'Meyer' zoysiagrass for top-growth, stolon growth, and for coverage rate. Zoysia, however, when established from plugs, which have a greater intact root structure than sprigs, benefitted little when K was applied to soil having moderate initial soil K levels (Fry and Dernoeden, 1987).

Many beneficial effects of K applied to bermudagrass during routine maintenance have been reported. Kiesling (1980) found that the initiation of new bermudagrass rhizomes and longevity of existing rhizomes on a low K soil were directly related to

increasing K applications. Leaf spot disease of bermudagrass has been shown to be much more severe where soil K levels have been kept low (Evans et al., 1964; Juska and Murray, 1974). Reduced dollar spot of bermudagrass by K applications was found by both Horn (1970) and Juska and Murray (1974). Increased K levels have been reported to decrease winter injury or increase winter hardiness (Adams and Twersky, 1960; Alexander and Gilbert, 1963; Gilbert and Davis, 1971; Juska and Murray, 1974).

The effects of K on visual turf quality and color appear less evident than on growth, cold resistance, and disease. Johnson et al. (1987) did not find any improvement of 'Tifway' bermudagrass within the soil K concentration range of 70 to 136 kg of K ha^{1}. Barrios and Jones (1980) also found no effect of K applications on the visual quality of bermudagrass. Sturkie and Rouse (1967) observed that both zoysia and bermudagrass have exhibited poorer color and early spring quality when K was not applied. While severe K deficiencies are observed in the absence of K fertilization, 'Tifgreen' bermudagrass appearance, growth, resistance to bermudagrass decline, and root weight were not improved by increasing K/N fertilization beyond a ratio of 0.5 to 1 (Snyder and Cisar, 2000). In addition, Sartain (2002) reported that K rates in excess of 0.50 to 0.67 times that of N application rates did not result in increased K uptake, shoot and root growth or visual quality of 'Tifway' bermudagrass.

Potassium is subject to leaching in many soils (Beard, 1982). Sartain (1996) reported that the mobility of K in USGA root-zone mixes may differ according to the nature of the anion associated with the K. Chung et al. (1999) in a simulated USGA root-zone mix reported a loss of 16% of applied K from 0-20-20, and between 8 and 11% from

applied monopotassium phosphate, potassium chloride, and potassium nitrate sources. In addition, Chung et al. (1999) observed that the anion charge associated with the K ion did not influence K leaching from selected K sources due to the limited quantity of anion exchange capacity associated with USGA root-zone mixes.

The CEC of a soil influences the ability of a soil to retain nutrient cations (Brady and Weil 1996). Petri and Petrovic (2001) reported that increasing the CEC level from less than 1 cmol kg^{-1} to 6 cmol kg^{-1} decreased K leaching exponentially. Furthermore, they did not observe additional K retention above 6 cmol kg^{-1}.

Phosphorus

In turfgrass, phosphorus is required in smaller amounts than N or K. Nevertheless, P is a vital component of cellular compounds. Phosphorus is required for photosynthesis, the interconversion of carbohydrates, fat metabolism, nutrient uptake, and oxidation reactions (Waddington et al., 1992). Jones (1980) suggests a sufficiency range of 3.0 - 5.5 g kg^{-1} for turfgrasses. For bermudagrass greens 1.5 to 2.4 g kg^{-1} tissue P is considered low with a range of 2.5 to 6.0 g kg^{-1} tissue P sufficient (Jones et al. 1991). Acceptable soil P as determined by Mehlich-I extractant ranges from 5 - 30 ppm (McCarty, 2001). Phosphorus is most readily available to plants in the soil pH range of 5.5 to 6.5 (Brady and Weil, 1996).

Phosphorus plays an important role in the vegetative establishment of warm-season grasses. Wood and Duble (1976) found that P affected St. Augustinegrass growth most during the first eight weeks of establishment. At eight weeks, coverage on plots receiving

little or no P averaged <50%, whereas plots receiving P averaged 73% coverage. Zoysiagrass establishment was also enhanced by P additions to a soil extremely low in P (Juska 1959). Phosphorus additions increased zoysia top, root, and stolon growth.

Responses to P additions on established turf are less consistent than N and K. In general, warm-season turfgrasses do not show dramatic growth responses to applied P (Pritchett and Horn, 1966). Sturkie and Rouse (1967) reported that zoysia and bermudagrass became lighter green as P rates increased. In addition, early season chlorosis of zoysia was caused by high rates of P. Cold tolerance of bermudagrass was increased by P additions as long as N and K are adequate (Gilbert and Davis, 1971). Pritchett and Horn (1966) reported that parasitic nematode infestations of turfgrass roots decreased as P additions increased, even with adequate initial soil P levels.

Phosphorus does not leach readily due to its low solubility in the soil solution of coated soils. Soil solution P is generally very low ranging from 0.001 mg P L^{-1} in very infertile soils to about 1.0 mg P L^{-1} in heavily fertilized soils (Brady and Weil, 1996). While losses of P in surface flow and runoff tend to be quite low, transport of P to groundwater is possible if excessive loading of P is applied to sandy soils with limited P sorption (Koehler et al., 1982; Peaslee and Phillips, 1981; Chung et al., 1999; Brown et al., 2000).

Because P leaching from golf courses could potentially contaminate ground and surface waters, several studies have explored P leaching potential under actual and simulated golf course conditions. Petrovic (1995) observed P concentrations in leachate from simulated fairways rarely exceeding analytical detection limits of 0.05 mg L^{-1}.

Using undisturbed soil columns simulating golf course fairway conditions, Starrett and Christians (1995) reported that irrigation rate affects P transport. Smith and Shuman (1998) observed P in leachate 30 to 50 days following application of soluble P in lysimeters located in functional USGA putting greens. Shuman (2001), reporting data from the same lysimeters, observed that high P concentrations in the leachate indicated that P leaches readily with 27% of the applied P accounted for in the leachate. Wong et al. (1998) reported that P concentrations in leachate of greens exceeded the surface water quality standard of 0.3 mg P L^{-1} using lysimeters reconstituted with soil collected from a golf course putting greens in Hong Kong. Furthermore, 37% of the applied P was accounted for in the leachate.

Water Use Efficiency

Water use efficiency (WUE) is defined as the quantity of dry matter produced per amount of water lost via evapotranspiration (g dry matter mL ET^{-1}). Turf water use rate may be influenced by species plant physiology, soil moisture availability, the degree of water demand, soil fertility, and cultural management practices. Estimating ET by measuring gravimetric weight changes and comparing it to tissue yield can be used to determine WUE.

The addition of amendments to sand based root zones may increase WUE by improving water retention and fertility. Huang and Petrovic (1991) reported increased WUE with the addition of clinoptilolite zeolite to sand. In addition, Comer (1999) observed improved WUE in zeolite-amended soils. Organic matter amendment, however, reduced WUE.

Stout and Schnabel (1997) investigated the effect of soil drainage and N fertilization on WUE of perennial ryegrass. They observed that denitrification caused by poor soil drainage conditions resulted in a 26% reduction in WUE during spring and a 20% reduction during a summer growth period. Sills and Carrow (1983) reported that perennial ryegrass WUE increased when water soluble N was applied and as N rate increased.

CHAPTER 3
MATERIALS AND METHODS

Glasshouse Studies

Glasshouse studies were utilized as both introductory exploratory studies and multi-year evaluations of root zone performance. The initial glasshouse study consisted of three phases, over a period of three years. The three phases consisted of Phase I (year one, 2000), an establishment period, Phase II (year two, 2001), a maintenance period, and Phase III (year three, 2002), a second maintenance period. A second glasshouse study, an artificially-coated sand rate study, was conducted in the spring of 2002 using selected rates of artificially-coated sand with and without sphagnum peat.

Phase I Year 2000

Twenty-four lysimeters were constructed at the Univ. of Florida's Envirotron Research Facility in Gainesville, FL, in the spring of 2000. The 45-cm tall by 15-cm in diameter cylindrical lysimeters consisted of a 30-cm root-zone placed over 15-cm of pea gravel. An intermediate "choker" layer was not used between the sand and gravel. A factorial design was used, with all combinations of two rates of sphagnum peat (0, 150 ml peat L^{-1} sand) and three types of coating (uncoated; naturally-coated; and artificially-coated sands). The uncoated sand was obtained from the Davenport, FL, mine of Standard Sand and Silica Co.; the coated sand was obtained from pit #5 in Orange county,

FL, Bishop and Buttrey, Inc., Orlando, FL; and the artificially coated was made by coating the uncoated sand listed above with a calcium-saturated montmorillonite clay (emathlite), (MFM Corp., Lowell, FL) at the rate of 40g clay kg^{-1} using a chemically-set epoxy resin (Bondo Marhyde Corp., Atlanta, GA) at 20 g kg^{-1} as the binder. The particle size range of the uncoated sand which was not artificially-coated was adjusted to approximately that of the finer textured naturally coated sand by sieving (Table 3-1). The artificially coated sand, however, was made from the unsieved, uncoated sand (Table 3-1). Treatments were replicated four times in a randomized complete block design resulting in 24 lysimeters as experimental units, each measuring 177 cm^2 in surface area. In addition to the experimental units, an extra set of "dummy lysimeters" (one per treatment) was constructed in the same manner as the experimental units for purposes of gathering physical property data without destroying the experimental units. The "dummy lysimeters" were not sprigged.

Establishment Phase

Each lysimeter was sprigged with 'Tifdwarf' bermudagrass at 5 g moist sprigs $lysimeter^{-1}$. Fertilizer was added at sprigging to supply 5 g N m^{-2}, 5 g P m^{-2}, and 10 g K m^{-2}. Additional N, P, and K were applied during the establishment phase of the study (Table 3-2). Ammonium sulfate, $NH_4H_2PO_4$ (MAP) , and KCl were used as the nutrient sources.

Bermudagrass coverage rate was evaluated 21, 29, 36, and 43 days after planting (DAP). Coverage scores (0 - 100%) were taken for each experimental unit based on visual observations.

Physical and chemical characterization. Prior to establishment, two undisturbed cores in brass rings were taken from each treatment using a double-cylinder hammer driven core sampler from one set of "dummy lysimeters" at depths 0 to15 cm and 15 to 30 cm. A total of 12, 3.0 x 5.56-cm cores were taken. Cores were stored in plastic bags and refrigerated until moisture release curves and saturated hydraulic conductivity (K_{sat}) were determined. The brass ring enclosed cores were installed in model 1400 Tempe cells (Soil Moisture Equipment, Santa Barbara, CA), saturated, and pressure was applied at increasing rates (0.3 - 1500 -kPa). Permanent wilting point was determined using 1500 -kPa chambers. K_{sat} was determined by ponding 6 cm of water on saturated soil cores and recording percolate collected with time. For conducting statistical analysis, the two depths were treated as replications.

Samples of each sand type were collected at construction to determine base-line soil chemical properties. Samples were analyzed for pH (1 soil:2 water), water-extractable P, and acetic acid-extractable P, K, Ca, and Mg by the University of Florida's IFAS Everglades REC soil testing laboratory, Belle Glade, Florida (Sanchez, 1990). In addition, oxalate extractable P, Fe, and Al was determined by ICAP after extraction at a 1:60 solid:solution ratio, following the procedures of McKeague et al. (1971). Detection limit for ICAP for P, Fe, and Al was 0.3, 0.03, and 0.02 mg kg^{-1}, respectively.

Water use efficiency. Determination of water use efficiency represents one measure of a plant's ability to obtain water from a particular growth media. Three water use efficiency trials were conducted following complete establishment to determine the degree to which the root zone mixes were able to provide water for clipping production.

Water use efficiency of turfgrass in treated soils was determined following the completion of the nutrient mobility study described below at week 11. Lysimeters were brought to pot water-holding capacity and weighed at the start of each WUE cycle. During each cycle the same quantity of water was added every 3 d to each lysimeter which maintained a moisture content 98% of that of field capacity. The quantity of water added was recorded and used as an estimation of the water used (Table 3-3). In addition, at the end of each cycle (varying from 2 - 4 weeks), lysimeters were weighed. This final weight was subtracted from the pot capacity weight, providing another estimate of water used which was recorded and added to the quantity of water applied during the cycle. Water use efficiency was calculated by dividing clipping yield produced during the cycle by the quantity of water used during the cycle.

Nutrient mobility. An evaluation of the mobility of P and K in selected treatments was initiated at sprigging. Lysimeters were maintained near field capacity using a timed overhead, mist irrigation system. Leaching was induced by applying a half pore volume ($\simeq$ 500 ml H_2O lysimeter^{-1}) of deionized water. Lysimeters were allowed to drain for 24 hr prior to leachate collection. The first leachate event occurred one wk following N, P, and K fertilization. Phosphorus and K were applied at 5 g P and 10 g K m^{-2} month^{-1} one wk prior to the first leachate event. Lysimeters were leached weekly for 10 wk., with only two random exceptions (wk 7 and 9). Leachate volume was recorded and 20 ml was decanted into scintillation vials and refrigerated until analysis. Leachates were analyzed for P and K using phosphomolybdate color-detection spectrophotometry for P and atomic adsorption spectrophotometry for K.

Plant tissue. Bermudagrass clipping were harvested 29, 43, 58, and 71 days after planting (DAP), i.e., bi-weekly. Mowing height was 20 mm and clippings were removed using stainless-steel scissors. The harvested leaf blade tissue was dried at 70° C for 48 h, weighed, and ground to < 2 mm. Total clipping production was determined as the summation of dried verdure harvest weights. For chemical analysis, 0.5 g of tissue were ashed at 450° C for 5 h. The ash was wetted with 1 ml of HNO_3, dried on a hot plate and reheated at 450° C for 2 h. Subsequently, the ash was dissolved in 0.1 M HCl and brought to 50 ml volume, and analyzed for P and K using phosphomolybdate color-detection spectrophotometry for P and atomic adsorption spectrophotometry for K. Uptake of P and K was calculated as the product of tissue concentration and the harvest weight.

Maintenance Period.

A maintenance period, during which data were not collected, began following completion of the water use efficiency study in order to age the treatments to determine the influence of time on treatment response. This period began on13 October 2000 (142 DAP) and ended on 1 May 2001 (342 DAP). During this period, N was applied biweekly with both P and K applications occurring monthly (Table 3-4). Ammonium sulfate, $NH_4H_2PO_4$ (MAP) , and KCl were the fertilizer sources used to supply each lysimeter with N, P, and K. Lysimeters were maintained near field-capacity using a mist irrigation system, and leached monthly by applying a half pore volume ($\simeq$ 500 ml H_2O lysimeter^{-1}) of deionized water to reduce potential salt build-up. Bermudagrass verdure was harvested weekly at a height of approximately 20 mm using stainless-steel scissors and discarded.

Phase II Year 2001

Nutrient mobility. A second evaluation of the mobility of P and K in selected treatments was initiated 342 DAP. Lysimeters were maintained near field capacity. Leaching was induced by applying a half pore volume ($\simeq$ 500 ml H_2O lysimeter^{-1}) of deionized water. Lysimeters were allowed to drain for 24 hr prior to leachate collection. Nitrogen, P, and K fertilization was applied 343 and 371 DAP (Table 3-5). The first leachate event occurred one week following N, P, and K fertilization. Lysimeters were leached 349, 356, 363, 371, 375, 381, 397, and 405 DAP. Leachate volume was recorded and 20 ml was decanted into scintillation vials and refrigerated until analysis. Leachates were analyzed using the same methods described for the Establishment Phase.

Plant tissue. Bermudagrass clippings were harvested bi-weekly 355, 370, 381, and 397 DAP at a height of approximately 20 mm using stainless-steel scissors. The harvested tissue was dried at 70° C for 48 h, weighed, and ground to < 2 mm. Total clipping production was determined as the summation of dried clipping harvest weights. The tissue was analyzed for P and K using the same methods described for the Establishment Phase. Uptake of P and K were calculated as the product of tissue concentration and the harvest weight.

Moisture stress and water use efficiency. A study to determine the number of days between irrigation and the number of days until wilting (ndw) was conducted from 16 July 2001 to 9 August 2001. On 16 July 2001 (419 DAP) lysimeters were brought to field capacity and application of irrigation water ceased. Clippings were harvested weekly in

which exhibited faster growth characteristics. N was applied, using only 20 mL of H_2O on 16 July 2001 supplementing a previous application of N, P, and K which occurred 2 wk earlier. Following visual determination of wilt, the date of wilt incidence and lysimeter mass were recorded. Harvested clippings along with terminal lysimeter mass were used to determine water use efficiency.

Maintenance Period.

A maintenance period, during which data were not collected, began following completion of the moisture stress study. This period began on13 August 2001 (447 DAP) and ended on 5 April 2002 (682 DAP). During this period N, P, and K applications occurred monthly (Table 3-6).

Phase III Year 2002

Nutrient mobility. A third evaluation of the mobility of P and K in selected treatments was initiated 682 DAP. Lysimeters were maintained near field capacity. Leaching was induced by applying a half pore volume ($\simeq$ 500 ml H_2O lysimeter^{-1}) of deionized water. Lysimeters were allowed to drain for 24 hr prior to leachate collection. Nitrogen, P, and K fertilization occurred 682, 715, and 747 DAP (Table 3-7). The first leachate event was imposed ten days following N, P, and K fertilization. Lysimeters were leached 692, 699, 704, 714, 718, 727, 739, and 761 DAP. Leachate volume was recorded and 20 ml was decanted into scintillation vials and refrigerated until analysis. As was done in the first leachate study, leachates were analyzed for P and K using phosphomolybdate color-detection spectrophotometry for P and A. A. for K.

Plant tissue. Bermudagrass verdure was harvested bi-weekly 699, 715, 729, and 746 DAP at a height of approximately 20 mm using stainless-steel scissors. The harvested tissue was dried at 70° C for 48 h, weighed, and ground to < 2 mm. Total clipping production was determined as the summation of dried clipping harvest weights. The tissue was analyzed for P and K using the same methods described for Phase I and II.

Moisture stress and water use efficiency. A second study to determine the number of days between irrigation and the appearance of leaf wilting (ndw) was conducted from 12 July 2002 to 8 August 2002. On 11 July 2002 (779 DAP) lysimeters were brought to field capacity and application of irrigation water ceased. N was applied, using only 20 ml of H_20 on 11 July 2001 supplementing a previous application of N which occurred 2 wk earlier. Following visual determination of wilt, the date of wilt incidence and lysimeter mass were recorded. Harvested clippings along with terminal lysimeter mass were used to determine water use efficiency.

Chemical soil characterization. Samples of each root zone mix were collected from the top 15 cm of each lysimeter upon completion of Phase III to determine soil chemical properties. Samples were analyzed for pH (1 soil:2 water), water-extractable P, and acetic acid-extractable P, K, Ca, and Mg by the University of Florida's IFAS Everglades REC soil testing laboratory, Belle Glade, Florida (Sanchez, 1990).

Cation exchange capacity. Cation exchange capacity of root zone mixtures was determined for the top 15 cm following completion of Phase III. Cation exchange capacity was determined by the unbuffered salt extraction method (Sumner and Miller, 1996). This procedure measures the CEC of the soil at its "field pH" value. Ammonium

chloride serves as the saturating reagent, and potassium nitrate is the displacing reagent.

Statistical analysis.

Statistical analysis of data was accomplished using ANOVA procedures (SAS, 1988). Means separation was accomplished using Duncan's Multiple Range Comparisons with $P > 0.05$.

Artificially-coated sand rate study 2002

Forty lysimeters were constructed at the Univ. of Florida's Envirotron Res. Facility in Gainesville, FL in the spring of 2002 using a different artificially-coated sand than was used in the previous glasshouse studies in order to permit a greater rate of emathlite clay coating. The artificially-coated sand material consisted of quartz sand coated with emathlite clay at the rate of 100 g clay kg^{-1}, with thermally-set Cascophen[R] resin (Borden Chemical, Inc., Columbus, OH) at 100g kg^{-1} as the binder. The 45-cm tall by 15-cm dia. cylindrical lysimeters consisted of a 30-cm root-zone placed over 15-cm of pea gravel. An intermediate "choker" layer was not used between the sand and gravel. Five rates of sand, artificially-coated with a Ca-saturated montmorillonite clay (emathlite) at 10 % by weight, were mixed with uncoated sand in a cement mixer to provide rates of 0, 125, 250, 500, and 750 ml artificially-coated sand L^{-1} total sand and two rates of peat 0 and 100 ml L^{-1} of final mix. Treatments were replicated in four randomized complete blocks resulting in 40 lysimeters as experimental units each measuring 177 cm^2 in surface area. Each lysimeter was sprigged with 'Tifdwarf' bermudagrass at 5 g moist sprigs $lysimeter^{-1}$. Fertilizer was added at sprigging to supply 5 g N m^{-2}, 5 g P m^{-2}, and 10 g K m^{-2}. Additional N, P, and K were applied during the study (Table 3-8). Ammonium

Nitrate, $(NH_4)_2SO_4$, $NH_4H_2PO_4$, and KCl were the fertilizer sources used to supply each lysimeter with N, P, and K. Bermudagrass coverage rate was evaluated 10, 17, 23, and 31 DAP. Coverage scores (0-100%) were taken for each experimental unit based on visual observations.

Physical characterization. Samples from each treatment were collected at construction to evaluate base-line soil physical properties. Each sample was put into a 5.0-cm diameter by 7.5-cm deep cylinder. The media were compacted by 15 drops of a 1.36-kg hammer from a height of 30 cm, and analyzed for saturated hydraulic conductivity, total pore space and pore space distribution, bulk density, and particle density, by USGA methods (Hummel, 1993).

Statistical analysis. Response data were analyzed by the linear-plateau model (Dahnke and Olson, 1990; Cerrato an Blackmer, 1990) using SAS PROC NLIN (SAS, 1988). Statistical analysis of physical characteristic data was accomplished using ANOVA procedures (SAS, 1988).

Field Studies

Field Study I 2001-2002

Establishment. Sixteen experimental plots were constructed at the Univ. of Florida's Fort Lauderdale Research and Education Center in Davie, FL in the fall of 2001 by expanding a previously described lysimeter facility from 12 to 16 plots (Snyder and Cisar, 1993). Plots 0.5-m wide by 2.0-m long, encased with plywood along the perimeter to a depth of 30 cm in order to hydraulically isolate the added soil mixtures from the surrounding root-zone media, constructed to USGA specifications, consisted of a 30-cm

root-zone placed over 5-cm of an intermediate "choker" layer and 15-cm of quartz pea gravel with one "40 quart stock pot" 35.6-cm inside diameter, 40.6-cm tall lysimeter in the center. The root-zone mix, choker layer, and pea gravel in each lysimeter was suspended on a perforated-metal stainless-steel plate, as has been previously described (Snyder and Cisar, 1993). Percolate was collected off-site under vacuum through a stainless-steel tube that extended to the bottom of the lysimeter. Treatments included uncoated sand, uncoated sand and peat (100 ml peat L^{-1}), naturally-coated sand and peat, and uncoated sand and peat amended with artificially coated sand (25% v/v). The uncoated and naturally-coated sand were obtained from the Golf Agronomics Ortona (uncoated) and Clermont (naturally-coated), FL blending facilities. The artificially-coated sand (Ca-montmorillonite, 10 % by weight) was similar to that used in the glasshouse rate study, previously described. Treatments were replicated in a latin square design resulting in 16 experimental units each measuring 1 m^2 in surface area. A latin square design was used in order to account for variability in two directions caused by increasing root zone depth from west to east and irrigation coverage from the north to south. Each experimental unit was sprigged with 200 g moist 'Tifdwarf' bermudagrass sprigs m^{-2} on September 24, 2001. Fertilizer was added at sprigging to supply 5 g N m^{-2}, 1.5 g P m^{-2}, and 2.7 g K m^{-2}. Additional N, P, and K using a complete fertilizer blend consisting of potassium nitrate, ammonium phosphate, and ammonium nitrate was the fertilizer source used to supply each experimental unit with N, P, K and micronutrients throughout the establishment phase, and once during the maintenance period at 103 DAP. Additional fertilizer applications during the maintenance phase consisted of only N in the

form of ammonium sulfate at 5.25 g N m^{-2}. The establishment phase spanned 91 days (0 to 91 DAP) with the maintenance period beginning at 92 DAP and extending to 213 DAP.

Bermudagrass coverage rate was evaluated 14, 21, 32, 38, 50, and 57 DAP. Coverage scores (0-100%) were taken for each experimental unit based on visual observations.

Soil moisture readings were measured using a Theta-Probe (Delta-T Devices Ltd, Cambridge, UK). Soil moisture readings were measured to a depth of 6 cm at various times throughout the establishment period and 12 h following 4:30 am irrigation events.

Physical soil characterization. Samples from each treatment were collected at the time of construction to evaluate base-line soil physical properties. Each sample was put into a PVC cylinder 5.0-cm diameter by 7.5-cm deep cylinder. The media were compacted and analyzed by USGA methods (Hummel, 1993).

At the completion of the study, undisturbed cores were taken from each experimental unit using a double-cylinder hammer driven core sampler at depths 0 to 15 cm for soil moisture characterization. A total of 16, 3.0 by 5.56-cm cores were taken. Cores were stored in plastic bags and refrigerated until moisture release curves could be determined. The cores were installed in model 1400 Tempe cells (Soil Moisture Equipment, Santa Barbara, CA), saturated, and pressure was applied at increasing levels (0.3 - 1500 -kPa). Moisture at permanent wilting point was determined using 1500 -kPa chambers.

Nutrient mobility. An evaluation of the mobility of P and K was initiated at sprigging. Collection of leachate was based on irrigation and rainfall amounts. Upon collection of leachate from the field lysimeters, leachate volume was recorded and 20 ml was decanted into scintillation vials. A drop of chloroform followed by refrigeration at 4° C preserved samples. Leachates were analyzed for P and K using phosphomolybdate color-detection spectrophotometry for P and atomic adsorption spectrophotometry for K.

Plant tissue. Bermudagrass clippings were harvested 39, 51, 58, 75, 82, and 89 DAP during the establishment period and 130, 143, 157, 170, and 187 DAP during maintenance at a height of 6.35 mm using a walk behind reel-type mower. The harvested tissue was oven dried at 60° C for 48 h, weighed and ground to < 2 mm in a stainless steel mill (Arthur Thomas Co., Philadelphia, PA), wet digested (Lowther, 1986) and analyzed for P and K using phosphomolybdate color-detection spectrophotometry for P and atomic adsorption spectrophotometry for K. Uptake of P and K were calculated as the product of tissue concentration and the harvest weight. Total clipping yield was determined as the summation of dried verdure harvest weights.

Chemical soil characterization. Samples of each root zone mix were collected at construction to determine base-line soil chemical properties. In addition, composite soil samples consisting of six samples 0 to 10 cm cores were taken from each plot using a 1.9-cm diameter sampler at the completion of the grow-in period (92 DAP) and maintenance period (215 DAP). Samples were analyzed for pH (1 soil:2 water), water-extractable P, and acetic acid-extractable P, K, Ca, and Mg by the University of Florida's IFAS Everglades REC soil testing laboratory, Belle Glade, Florida (Sanchez, 1990).

Cation exchange capacity. Cation exchange capacity of root zone mixtures was determined prior to construction and at the completion of the maintenance period (215 DAP). Cation exchange capacity was determined by the unbuffered salt extraction method (Sumner and Miller, 1996). This procedure measures the cation exchange capacity of the soil at its "field pH" value. Ammonium chloride serves as the saturating reagent, and potassium nitrate is the displacing reagent.

Statistical analysis. Statistical analysis of data was accomplished using ANOVA procedures (SAS, 1988). Means separation was accomplished using Duncan's Multiple Range Comparisons with $P \leq 0.05$.

Field Study II: 2002

A second field study trial was conducted during summer and fall 2002. Upon completion of field study I, sod and soil were removed from each of the 16 plots to a depth of 10 cm. Vapam, a soil fumigant, was used to kill any remaining plant material. The Vapam was applied at 100 ml Vapam m^{-2} and the plots were covered with plastic, stapled to the wooden frame which isolates the plots from the surrounding green, and sand was placed on the surface of the plastic around the plot perimeter to assist in retention of the Vapam vapor. The plastic was removed 72 h following Vapam application. Any remaining plant material was removed using a three pronged hand weeder and discarded. The plots were re-leveled with additional amounts of the appropriate root-zone mixture prior to planting. On June 7, 2002 plots were sprigged with 200 g moist cv. Tifdwarf bermudagrass sprigs m^{-2}. Fertilizer was added at sprigging to supply 5 g N m^{-2}, 1.5 g P m^{-2}, and 2.7 g K m^{-2} using the same fertilizer source described

for Field Study I, and was the fertilizer source used to supply each experimental unit with N, P, K and micronutrients weekly throughout the establishment period. Biweekly fertilizer applications during the maintenance period consisted of only N in the form of ammonium sulfate at 5.25 g N m^{-2}. The establishment period spanned 90 days (0 to 90 DAP), and the maintenance period commenced at 91 DAP.

Percent bermudagrass cover was determined 13, 26, 34, 40, 47, 55, 62, 69, and 76 DAP. Cover scores were taken for each experimental unit based on visual observations.

Soil moisture readings were measured using the Theta-Probe. Soil moisture readings were measured at various times throughout the establishment period and 12 h following 4:30 am irrigation events.

Physical characterization. Samples from each treatment were collected at construction to evaluate base-line soil physical properties by USGA methods (Hummel, 1993).

Nutrient mobility. An evaluation of the mobility of P and K was initiated at sprigging. Collection of leachate was based on irrigation and rainfall amounts. Upon collection of leachate from the field lysimeters, leachate volume was recorded and 20 ml was decanted into scintillation vials. A drop of chloroform followed by refrigeration preserved samples. Leachates were analyzed for P and K using phosphomolybdate color-detection spectrophotometry for P and atomic adsorption spectrophotometry for K.

Plant tissue. Bermudagrass clippings were harvested 28, 34, 41, 47, 55, 62, 69, 76, 83, and 90 DAP during the establishment period and weekly during maintenance at a height of 7.87 mm using a walk behind reel-type mower. The harvested tissue was oven

dried at 60° C for 48 h, weighed and ground to < 2 mm in a stainless steel mill, wet digested (Lowther, 1986,) and analyzed for P and K using phosphomolybdate color-detection spectrophotometry for P and atomic adsorption spectrophotometry for K. Uptake of P and K were calculated as the product of tissue concentration and the harvest weight. Total clipping production was determined as the summation of dried verdure.

Chemical soil characterization. Samples from each treatment were collected at the start of the second field study to evaluate base-line soil chemical properties. In addition, composite soil samples consisting of six samples 0 to 10 cm were taken from each plot using a 1.9-cm diameter core sampler at the completion of the grow-in period (90 DAP) and maintenance period (180 DAP). Samples were analyzed for pH (1 soil:2 water), and acetic acid extractable P, K, Ca, and Mg by the University of Florida's IFAS Everglades REC soil testing laboratory, Belle Glade, Florida (Sanchez, 1990).

Bromide and rubidium. On August 8, 2002 (62 DAP) sodium bromide and rubidium chloride were applied at 15 g NaBr m^{-2} and 2 g Rb m^{-2} in order to monitor water movement and investigate cation exchange characteristics of the root-zone mixtures. Soil samples were taken from each plot 42 days after application (DAA) and extracted for Rb using acetic acid as stated above. Leachates and soil were analyzed for Br and Rb using a Br specific electrode and atomic adsorption spectrophotometry for Rb.

Cation exchange capacity. Cation exchange capacity of root zone mixtures was determined prior to the second field study and at the completion of the maintenance period (180 DAP). Cation exchange capacity was measured using the unbuffered salt extraction method (Sumner and Miller, 1996).

Table 3-1 Particle size distribution of sand types used in Phase I - III, 2000-2002.

Type	FG	VCS	CS	MS	FS*	FS**	VFS*	VFS**	Silt+clay
	------	------	------	------	%	------	------	------	
Uncoated Sand	0.0	0.1	12.9	20.6	22.8	22.8	2.3	0.1	0.0
Naturally-Coated Sand	0.0	0.0	5.9	64.0	25.3	29.0	4.6	0.9	0.2
Artificially-Coated Sand	0.0	0.1	20.6	55.2	19.1	21.7	3.9	1.3	1.1

* By the USGA classification system

** By the USDA classification system

Table 3-2 Nitrogen, phosphorus, and potassium applied during phase I 2000.

Week	N†	P‡	K‡
	---------- g m^{-2} ----------		
1 - 4	10.0	5.0	10.0
5 - 8	10.0	2.5	10.0
9 - 12	7.5	1.2	5.0
13 - 16	10.0	1.2	5.0
17 - 20	10.0	1.2	5.0
Total	47.5	11.3	35.0

†Applied biweekly
‡Applied monthly

Table 3-3 Total quantity of water applied to lysimeters during water use efficiency trials in phase I 2000.

Water Use Efficiency Trial	Total water applied
	- - g $lysimeter^{-1}$ - -
3 - 16 Aug	550
17 Aug - 14 Sept	1260
15 Sept - 12 Oct	695

Table 3-4 Nitrogen, phosphorus, and potassium applied during maintenance period 2000 - 2001 following phase I 2000.

Month	Days after Planting	N†	P‡	K‡
		- - - - - - - - - - g m^{-2} - - - - - - - - - -		
October	142 - 160	10.0	1.2	5.0
November	161 - 191	10.0	1.2	5.0
December	192 - 222	10.0	1.2	5.0
January	223 - 253	10.0	1.2	5.0
February	254 - 281	10.0	1.2	5.0
March	282 - 312	10.0	1.2	5.0
April	313 - 341	10.0	1.2	5.0
Total		70.0	8.4	35.0

†Applied biweekly
‡Applied monthly

Table 3-5 Nitrogen, phosphorus, and potassium applied during phase II 2001.

Week	N†	P‡	K‡
	- - - - - - - - - - g m^{-2} - - - - - - - - - -		
1 - 4	10.0	5.0	10.0
5 - 8	10.0	2.5	10.0
9 - 12	10.0	1.2	5.0
13 - 15	0.0	0.0	0.0
Total	30.0	8.2	25.0

†Applied biweekly
‡Applied monthly

Table 3-6 Nitrogen, phosphorus, and potassium applied during maintenance period following phase II 2001.

Month	Days after Planting	N†	P‡	K‡
			$g\ m^{-2}$	
August	447 - 465	10.0	1.2	5.0
September	466 - 495	5.0	1.2	5.0
October	496 - 526	10.0	1.2	5.0
November	527 - 556	5.0	0.0	0.0
December	557 - 587	10.0	1.2	5.0
January	588 - 618	10.0	1.2	5.0
February	619 - 646	10.0	1.2	5.0
March	647 - 677	5.0	1.2	5.0
Total		65.0	8.4	35.0

†Applied biweekly
‡Applied monthly

Table 3-7 Nitrogen, phosphorus, and potassium applied during phase III 2002.

Week	N†	P‡	K‡
	---------- g m^{-2} ----------		
1 - 4	10.0	5.0	10.0
5 - 8	10.0	2.5	10.0
9 - 12	7.5	1.2	5.0
13 - 16	5.0	0.0	0.0
17	0.0	0.0	0.0
Total	32.5	8.7	25.0

†Applied biweekly
‡Applied monthly

Table 3-8 Nitrogen, phosphorus, and potassium applied during artificially-coated sand rate study.

Days after planting	N†	P‡	K‡
	---------- $g\ m^{-2}$ ----------		
0 - 10	10.0	5.0	10.0
10 - 20	5.0	0.0	0.0
20 - 31	0.0	0.0	0.0
Total	10.0	5.0	10.0

†Applied biweekly
‡Applied monthly

CHAPTER 4
RESULTS AND DISCUSSION

Glasshouse Study: Phase I Year 2000

Physical Characterization of Root-Zone Medium in Undisturbed Cores

Saturated hydraulic conductivity (K_{sat})

Neither peat nor coating affected K_{sat} (Table 4-1). For K_{sat} there was no interaction ($P > 0.05$) between the main effects of peat and coatings. The K_{sat} of all treatments exceeded the accelerated range of 30-60 cm hr^{-1} specified for putting green root zone mixes by the USGA (USGA Green Section Staff, 1993). This indicates that the sand grain coatings, natural or artificial, and peat did not reduce root zone percolation rate over the short term. Bigelow et al. (2000) observed a decrease in percolation rate when sand was amended with peat, however, no effect of peat on K_{sat} was observed. A lack of compaction of the experimental columns may have led to the high K_{sat} values and lack of differentiation among the treatments (Brown and Duble, 1975).

Volumetric water content

The volumetric water content of all undisturbed samples decreased as water potential became more negative (Table 4-2, Fig 4-1). At certain water potentials differences were noted among the treatments. Since there were no interactions among the main effects, except at -1500 kPa, only main effect means are presented. The interaction

at -1500 kPa occurred because the uncoated sand with peat contained much more water relative to the uncoated sand without peat than the comparisons of the two coated sands with and without peat, i.e., the interaction was one of magnitude, not direction.(data not presented). Peat increased water retention at all pressures (Table 4-2, Fig 1). For the artificially-coated sands there was a greater decrease in water content between -0.3 and -3.0 kPa than was found for the other sands, which was likely due to the larger particle size of the sand which was coated. But, at < - 4 k Pa, the artificially-coated sands retained significantly more water than uncoated sands. At a water potential of -10 kPa (field capacity), artificially-coated sand with peat had the greatest water retention. Thus, at low tensions, where aeration could be a problem because of water displacing air from soil pores, the artificially-coated sand did not hold as much water as uncoated sand. However, the artificially-coated sand held water well at higher tensions which generally are associated with problems of insufficient moisture. Bigelow et al. (2000) suggested that an ideal soil or amendment is one that releases water at low tensions and retains significant amounts at moderate tension. In general, there was no difference in water content of the uncoated and naturally-coated sands.

Chemical Soil Characterization

The pH of all sand types were in the acidic range with artificially-coated sand having the lowest pH (Table 4-3). Uncoated sand had the highest pH, most likely because of the pH of water used for pH measurement. Since the uncoated sand and clay had pH values of 6.4 and 7.0, respectively, the low pH of the artificially-coated sand probably originated from the polymer coating due to residual acidity following

polymerization. Being a proprietary product, the detailed chemistry of the polymer is not available.

The cation exchange capacities of sand varied with coating type (Table 4-3). Artificially-coated sand had greater CEC than naturally-coated sand. The higher CEC of the artificially-coated sand relative to the naturally-coated sand stems from the type of clay and the amount of coating present. Low CEC kaolinitic type clay predominate the surface of naturally-coated sand whereas a higher CEC montmorillonitic type clay was used to coat the artificially-coated sand. In addition, less than 2 % silt plus clay generally constitute natural coatings while the artificially-coated sand was coated with 4 % clay by weight. Uncoated sand had the lowest CEC.

Phosphorus and K concentrations of the naturally occurring uncoated and naturally-coated sand were less than that of the artificially-coated sand (Table 4-3). Both uncoated and naturally-coated sand had low background levels of water soluble P, extractable P, and K. In contrast, artificially-coated sand had higher levels of extractable and water soluble P and K than uncoated and naturally-coated sand. Greater P content of artificially-coated sand can likely be attributed to P rich clay (4.03% P_2O_5) (MFM Corp., Lowell, FL) used and perhaps some contribution coming from the polymer.

Oxalate extractable Al and Fe was generally greatest for naturally-coated sand indicating a high level of P sorption (Table 4-4). Uncoated and artificially-coated sand oxalate extractable Fe were below detection limit (bdl) of 0.02 mg kg. Oxalate extractable P value of artificially-coated sand confirms high soil test P observed previously (Table 4-2).

Bermudagrass Percent Coverage

Rapid establishment is critical both for agronomic and financial reasons. For example, rapid turf establishment reduces the invasion of weed species (Beard, 1982). In addition, the opening of a turf area for play hinges on the establishment rate of the turf. For purposes here, coverage is defined as the lysimeter surface area overlain with bermudagrass.

Although several authors have observed an increase in percent coverage because of peat (Nus et al., 1987; Bigelow et al., 2000; Waltz and McCarty, 2000; Brown et al., 2000), the inclusion of peat in the sand root zone mixture did not influence percent coverage in this glasshouse study (Table 4-5). Establishment was, however, affected by the presence of coatings. Possibly, the reduced ability of the uncoated sands, with and without peat, to retain moisture near the surface at higher moisture tensions (Fig 4-1) hindered the ability of the grass to establish quickly. Brown et al. (2000) also observed greater bermudagrass percent coverage in the presence of sand grain coatings. However, since peat did not influence percent coverage, and the frequent irrigation used during establishment, the reason for the difference may be more nutritionally related.
Along with water, P plays a critical role in the establishment of warm-season turfgrasses (Turner and Hummel, 1992). As will be discussed later, naturally-coated sands retain more P than uncoated and artificially-coated sand, which also may have affected percent coverage.

Clipping Yield

Since only one interaction between the main effects (peat and coating) was observed (43 d after planting), only main effect means are presented. The interaction occurred on the 43 DAP harvest because on that date harvested biomass was greater in the naturally-coated sand without peat than in naturally-coated sand with peat (data not presented). Total clipping yield over the four harvest periods was greater in root zones amended with peat than in those without peat (Table 4-6). Brown et al. (2000) also observed an increase in total clipping yield when peat was added regardless of the presence of coating. The effect of peat was most pronounced during the first 29 d, when water availability and retention was critical to the establishment of newly planted sprigs. This more precise measurement of bermudagrass growth supports previous findings in which turfgrass establishment rate was increased by peat ((Nus et al., 1987; Bigelow et al., 2000; Waltz and McCarty, 2000; Brown et al., 2000) but was not detected by visual observations in this study.

An effect of coating on clipping yield was observed on each of the four harvest periods (Table 4-6). The presence of sand grain coatings increased clipping yield well into establishment. With the exception of the final harvest, more clipping yield was produced with the two coated sands than with the uncoated sand. In addition, more total clipping yield was produced from naturally-coated sand than artificially-coated sand. This effect of coating on clipping yield production was likely the result of the improved retention of water (Table 4-2) and nutrients (data to be presented below).

K Leaching

There was no interaction among the treatments peat and coating, so only main effect means are presented (Table 4-7). It appears that the measured CEC characteristics of artificially- and naturally-coated sand (Table 4-3) reduced K loss at 7 DAP. More than 20% of the applied K was leached from the uncoated sand. Less than 4% of the applied K was leached from the artificially-coated sand. Less K was leached from the naturally-coated sand than the uncoated sand.

At 14 DAP, the greatest quantity of K was leached from uncoated and naturally-coated sand. The quantity of K leached from naturally-coated sand did not increase compared with the first leachate. Moreover, the lack of differentiation between uncoated and naturally-coated sand was probably the result of large quantity of K already leached by 7 DAP, making less available for leaching 14 DAP.

Less K was leached from all treatments 21 DAP, probably due to diminishing K quantities in the root zone mixes. No difference in K leached was observed between naturally-coated and uncoated sand. Twenty-eight DAP less K leached from artificially-coated sand than uncoated sand.

At 30 DAP, N, P, and K were reapplied. This influx of K provided similar statistical separation of treatments on 35 DAP as occurred at 7 DAP, which also followed K fertilization. There appeared to be less K leaching 35 DAP, perhaps because of greater K uptake by a more dense stand of turf. Less K was leached from the naturally- and artificially-coated sands, indicating that the coatings present on the sand grain surface were reducing K leaching. At 35 DAP, a peat x coating interaction showed that peat

greatly reduced K leaching from uncoated sand (2.24 g K m^{-2} without peat vs 0.89 g K m^{-2} with peat), whereas peat had little effect on leaching from the coated sands (0.15 [no peat] vs 0.20 [peat] and 0.33 [no peat] vs .033 [peat] for the artificially- and naturally-coated sands, respectively (Table 4-8).

The leachates at 49 and 56 DAP were similar to previous leaching events which occurred following large K losses several weeks after K application, in that statistical separation between treatments decreased with time following K fertilization. Potassium leaching was decreased by peat for the coated sands, whereas K leaching was increased by the presence of peat in the uncoated sand. This may have occurred because of leaching of K that was weakly adsorbed by peat during the previous leaching events, and which ultimately only leached in the absence of coating on the sands.

Potassium was applied at half the previous rate 56 DAP, i.e. 2 wk prior to 70 DAP. The greatest quantity of K was leached from uncoated sand. The presence of sand grain coatings once again proved critical in reducing K leaching losses. The same type of interaction among main effects occurred during the eighth leaching as occurred during the fifth event, which also was the first leaching event after a fertilization (Table 4-7). Peat greatly reduced K leaching in the uncoated sand, but did not do so for coated sands (Table 4-7). The greatest quantity of K was leached from uncoated sand. Chung et al. (1999) reported that 11% of total K, applied as KCl, was leached from bermudagrass grown on a USGA root-zone mix containing uncoated sand as compared to 31% reported in this study for uncoated sand and 16% for naturally-coated sand. Only 4% of the applied K was leached from artificially-coated sand.

Total K leached was not reduced by peat (Table 4-7). Bell (1959) demonstrated that trivalent and divalent cations were absorbed much more strongly by Sphagnum than monovalent ones.

K Uptake

The presence of coatings and the inclusion of peat influenced K uptake (Table 4-9). At 29 DAP, the greatest quantity of K uptake occurred in the naturally-coated sand, and greater K uptake occurred in artificially-coated sand than in uncoated sand. Moreover, the lowest concentration of tissue K was observed in the uncoated sand treatment (Table A-1). Tissue K concentration ranged from 10.0 to 14.6 g K kg^{-1} which is within the sufficiency range of 10 to 30 g kg^{-1} in bermudagrass tissue reported by Sartain, 1999. Tissue K concentration did not differ between naturally- and artificially-coated sand 29 DAP (Table A-1).

Potassium uptake increased as clipping production increased (Table 4-6) 43 and 58 DAP. Potassium uptake by bermudagrass growing in artificially- and naturally-coated sand was greater than uptake in uncoated sand. Artificially- and naturally-coated sand improved K tissue concentration over that of uncoated sand (Table A-1).

The fourth harvest, 71 DAP, occurred 2 wk following K reapplication. Uptake of K from uncoated sand was the lowest compared with the other treatments. However, K uptake improved in comparison to the 29 and 58 DAP harvest dates. This increase in K uptake was likely the result of delaying the scheduled leachate event 1 wk, thereby

allowing a total of 2 wk between K application and leaching. Delaying the leaching event meant that K was not leached from the root zones of uncoated, naturally-coated, and artificially-coated sands, and was therefore, available for plant uptake.

P Leaching

The low P retention capacity of USGA greens is often a source of criticism. Brown et al. (2000) reported that the use of coated sands in a USGA root zone mix increased P retention relative to uncoated sand. Monoammonium phosphate (MAP) was not included as a source of P in the Brown et al. (2000) study. In the present study, which used MAP as the P source, reduced P leaching in the presence of naturally-coated sand also was observed (Table 4-10).

Although there was a peat x coating interaction for five leaching events, only main effect means are presented in Table 4-10. Peat x coating interactions are presented in Table 4-11. The greatest quantities of P leaching occurred in those leachate events which followed the application of P. Seventeen percent of the 2.5 g P m^{-2} which was applied to uncoated sand prior to leaching was lost 7 DAP. Chung et al. (1999) observed a loss of 8 % of applied P as MAP from an uncoated sand and peat (85:15) USGA mix from a leaching event which directly followed P application. Large quantities of P were leached from artificially-coated sand 7 DAP. Phosphorus losses from artificially-coated sand are likely attributed to the integral P content of the artificially-coated sand associated with the clay (Table 4-3). No P loss was observed for the naturally-coated sand. Reduced P leaching from naturally-coated sand can be attributed to high oxalate extractable Fe and Al (Table 4-4).

A greater quantity of P continued to leach from artificially-coated sand than any other treatments from 14 to 28 DAP. In addition, more P was leached from uncoated sand with and without peat than naturally-coated sand.

The leachate event 35 DAP occurred 1 wk following a second application of P at 2.5 g P m^{-2}. P leached from uncoated sand increased relative to that determined 28 DAP. Artificially-coated sand continued its trend of P loss 35 DAP. The naturally-coated sands continued to reduce P loss.

Similar results were observed for leachate events occurring 49, 56, and 70 DAP. Naturally-coated sand showed better P retention over that of uncoated and artificially-coated sand.

For most of the leaching events, and for the total leaching, peat increased P leaching. Brown et al. (2000) also observed greater P leaching in the presence of peat additions. For certain leaching events and for total leaching, however, there were interactions between the main effects peat and coating with regard to P leaching. On leaching events 14, 21, and 28 DAP, peat resulted in more P leaching, but the magnitude of the increase relative to no peat varied inconsistently with coating. But for the leaching events 35 and 70 DAP, peat resulted in less leaching of P in uncoated sand, whereas it was generally associated with more leaching of P in the coated sands.

Perhaps, the total quantity of P leached over eight leaching events provides a more clear picture of the influence of each treatment on P retention. The greatest quantity of P was leached from artificially-coated sand, and a greater quantity of P was leached from uncoated sand than from the naturally-coated sand. More P was leached when peat was in

the mix, likely due to P mineralization. Clymo (1963) observed that the chemical nature of sphagnum exchange sites appear to be unesterified polyuronic acids in the cells walls and went on to demonstrate that anion exchange in Sphagnum was very weak with P ions absorption only occurring by living Sphagnum leaves. Furthermore, Nichols and Boelter (1982) noted that peats low in Al and Fe exhibit very low P reduction capabilities, as the organic fraction had almost no P absorption capacity.

P Uptake

Phosphorus is generally required is smaller amounts than K. Phosphorus tissue content sufficiency ranges between 3.0 - 5.5 g kg^{-1} (Turner and Hummel, 1992). Coating and peat had an effect on P uptake (Table 4-12).

Since there were no interactions between the main effects peat and coating, only means for main effects are presented. During the first harvest period (29 DAP), the greatest P uptake occurred from naturally- and artificially-coated sands. Uncoated sand had the smallest quantity of P uptake probably because less P was retained in the root zone and because there was less clipping yield produced. Tissue P concentration from uncoated sand was less than the critical value of 3.0 g kg^{-1} for P sufficiency (Turner and Hummel, 1992) (Table A-2). Although mean tissue P concentration from naturally-coated sand was greater than the critical value of 3.0 g kg^{-1}, there was no statistical difference in tissue P concentration between uncoated and naturally-coated sand.

Artificially-coated sand improved P uptake 43 DAP. Despite the marked reduction in P leached from naturally-coated sand, P uptake did not improve from this treatment at 43 DAP, indicating that P retained in the root zone was not immediately

available for plant uptake. Tissue P concentration from naturally-coated sand was less than that of uncoated sand 43 DAP (Table A-2). It appears that P sorbed by naturally-coated sand is resistant to desorption (Harris et al., 1996) thereby reducing its availability and absorption by plants, whereas in artificially-coated sand uptake is not so severely reduced. At 58 DAP, however, P uptake was greater in naturally-coated sand than uncoated sand. However, since, there was no difference in tissue P concentration between naturally-coated and uncoated sand 58 DAP (Table A-2), greater P uptake from naturally-coated sand occurred because of greater clipping production (Table 4-6) (Russell, 1977). Phosphorus uptake and tissue P concentration was still the greatest in artificially-coated sand 58 DAP.

Phosphorus was applied two weeks prior to the fourth harvest (71 DAP) with only one leachate event occurring between P reapplication and harvest. As with K, P uptake improved as a result of this delay. There was no difference among treatments, except peat, at 71 DAP. In addition, tissue P concentration was greater than 3.0 g kg^{-1} in all treatments. Tissue P concentration from artificially-coated sand remained greater than that of naturally-coated sand (Table A-2).

The presence of peat in the root zone mixture increased P uptake (Table 4-12). The observed increase in P uptake is best explained by increased clipping production of bermudagrass in the presence of peat (Table 4-6). Peat only improved tissue P concentration once during Phase I (43 DAP). Finally, peat increased total P uptake.

Water Use Efficiency

In all three trials conducted during glasshouse study Phase I, greater water use efficiency was observed when peat was incorporated into the root zone mixes (Table 4-13). Peat has a high water holding capacity, retaining up to 20 times its dry weight (Brady and Weil, 2000). In addition, water held by peat is readily available for plant use (Brady and Weil, 2000). The ability of peat to provide such benefits over a long period of time, however, is uncertain. Sphagnum peat is sold in a relatively undecomposed state. Maas and Adamson (1972) reported that sphagnum peat was stable after 36 mo incubation. Horn (1970), however, observed that in Florida, where warm temperatures, high rainfall, and high microbial activity exist, peat additions to soils are may be oxidized within one year.

Since an interaction between main effects (peat, coating) was observed only on 14 September, only main effect means are presented (Table 4-13). In the first WUE trial naturally-coated sand had greater WUE than both uncoated and artificially-coated sand (Table 4-5). However, for the 14 September trial, the WUE for naturally-coated sand without peat was less than that for artificially-coated sand without peat (data not presented). The duration of the first WUE trial was only 2 wk and may not have provided enough time for treatment separation. All treatments separated in the second WUE trial which was conducted over a 4 wk period. Coated sands had greater WUE values than uncoated sand. The third WUE trial was also conducted over a 4 wk period, but, only an effect of peat was observed. For undetermined reasons, an effect of coating was not observed. Perhaps due to late season conditions there may have been less water demand.

Summary: Phase I

The presence of sand grain coatings influenced many of the responses studied in Phase I. K_{sat}, however, was not influenced by sand grain coatings. Perhaps because of a greater degree of clay coating, artificially-coated sand had greater moisture retention than naturally-coated and uncoated sand. There was a difference in moisture retention detected between naturally-coated and uncoated sand. Sand grain coatings increased bermudagrass establishment rate and clipping production. Increases in water use efficiency were also observed. Sand grain coatings reduced K leaching and increased K uptake. Naturally-coated sand greatly increased P retention relative to uncoated sand, but this increase in P retention did not always translate into greater P uptake because of reduced availability. Tissue P concentration from naturally-coated sand were never greater than that of uncoated sand. The greatest P leaching occurred from artificially-coated sand. The presence of artificially-coated sand did, however, improve P uptake and tissue P concentration relative to uncoated and naturally-coated sand.

Peat also influenced responses studied in Phase I. As with coatings, peat did not reduce K_{sat}. Peat improved the water holding capacity of all sand types. Peat also improved clipping production during the early days of establishment. Peat, however, was not observed to increase percent coverage. In all trials, peat increased water use efficiency. Peat improved the poor K leaching characteristics of uncoated sand by buffering the loss of K immediately following K fertilization. Phosphorus leaching increased in the presence of peat. Finally, peat increased P and K uptake. Peat, however, was only observed to increase tissue P concentration once (43 DAP) during phase I 2000.

Table 4-1 Effect of coating and peat on saturated hydraulic conductivity.

Peat	K_{sat}	Sand coating	K_{sat}
	- -cm h^{-1}- -		- -cm h^{-1}- -
With	79.8a†	Uncoated	73.0a
Without	73.2a	Naturally	76.3a
		Artificially	80.2a

†Any means within the same column and main effects (peat and sand coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-2 Effect of coating and peat on root-zone mix water retention.

	Water potential (-k Pa)										
Main effects	0.3	2	3	4	6	8	10	15	20	34	1500
	- - - - - - - - - - - - - - - - Volumetric water content (%) - - - - - - - - - - - - - - - -										
Peat											
With	41.8a†	26.8a	16.6a	11.1a	9.3a	8.5a	8.1a	7.4a	7.1a	6.2a	2.5‡
Without	37.4b	22.8b	13.7b	6.9b	5.4b	4.8b	4.6b	4.0b	3.8b	3.3b	1.2
Sand coating											
Uncoated	38.0b	28.8a	16.6a	7.3b	5.7c	5.3b	5.1b	4.8b	4.6b	4.3b	1.7
Naturally	38.6b	28.4a	16.6a	9.4a	7.1b	6.1b	5.6b	4.8b	4.5b	3.9b	1.4
Artificially	42.2a	17.1b	12.2b	10.3a	9.4a	8.6a	8.2a	7.6a	7.2a	6.0a	2.3

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

‡Comparisons among main effects (Peat and Sand Coating) are not made due to interactions between main effects.

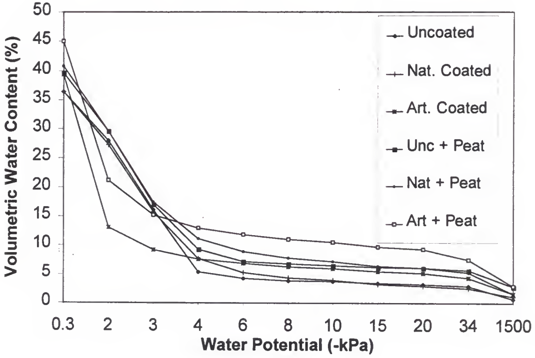

Fig. 4-1. Water release curve of undisturbed core root zone samples collected April 2000. Nat., Art., and Unc., refer to naturally, artificially, and uncoated sand, respectively.

Table 4-3 Soil chemical properties of materials used in glasshouse study.

Type	pH	CEC	Pa	Pw	K
		$cmol_c\ kg^{-1}$	- - - - - - - - - mg L^{-1} - - - - - - - - -		
Uncoated sand	6.4	0.0	2	1	2
Naturally-coated sand	5.4	4.5	2	1	4
Artificially-coated sand	3.8	10.4	555	43	9
Ca-Montmorillonite clay	7.0	69.8	758	5	52

Pa, K - acetic acid-extractable P
Pw - water extractable P

Table 4-4 Oxalate extractable P, Al, and Fe of sands used in Phases I-III.

Type	P	Al	Fe
	- - - - - - - - - - - - - - - mg kg^{-1} - - - - - - - - - - - - - - -		
Uncoated sand	21.6(± 4.24)	3.0(±0.00)	bdl†
Naturally-coated sand	23.3(±0.20)	198.1(±1.14)	178.2(±1.02)
Artificially-coated sand	472.8(±10.2)	32.3(±0.9)	bdl
Emathlite Clay	12230(± 430)	3006(± 126)	1561(± 179)

† bdl signifies that instrument reading fell below detection limit.

Table 4-5 Influence of peat and coating main effects on visual rating of coverage as a function of time after planting phase I 2000.

	Days after planting			
Main effects	21	29	36	43
	- - - - - - - - - - - - - - % - - - - - - - - - - - - - - -			
Peat				
With	25a†	40a	70a	83a
Without	16a	37a	70a	82a
Sand coating				
Uncoated	9b	21b	57b	69b
Naturally	38a	58a	80a	91a
Artificially	14b	35b	72a	88a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-6. Influence of peat and coating main effects on clipping yield of bermudagrass as a function of time after planting phase I 2000.

	Days after planting				
Main effects	29	43	58	71	Total
	$g\ m^{-2}$				
Peat					
With	114a†	212‡	197a	118a	642a
Without	69b	191	129b	95a	485b
Sand coating					
Uncoated	20c	137	128b	82b	369c
Naturally	164a	247	186a	135a	734a
Artificially	90b	220	176a	101b	588b

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-7 Influence of peat and coating main effects on K leached as a function of time after planting, for K fertilization 0, 30, 57 days after planting phase I 2000.

Main effects	Days after planting									
	7	14	21	28	35	49	56	70	Total	Leached
	------------------- $g\ m^{-2}$ -------------------									%
Peat										
With	0.97a†	0.73a	0.47a	0.45a	0.91‡	0.39a	0.20‡	0.09‡	5.07a	14
Without	1.57a	0.84a	0.42a	0.26a	0.48	0.44a	0.18	0.45	3.78a	11
Sand coating										
Uncoated	2.30a	1.15a	0.64a	0.55a	1.57‡	0.66a	0.30	0.72‡	7.90a	23
Naturally	1.12b	1.00a	0.56a	0.37ab	0.33	0.47a	0.20	0.03	4.08b	12
Artificially	0.38b	0.20b	0.13b	0.15b	0.17	0.10b	0.08	0.07	1.30c	4

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

‡Comparisons among main effects (Peat and Sand Coating) are not made due to interactions between main effects.

Table 4-8 Interaction of peat and coating main effects on K leached as a function of time after planting for fertilization applied 0, 30, and 57 days after planting phase I 2000.

Main effects		Days after planting							
		7	14	21	28	35	49	56	70
Interaction means		------------------- $g\ m^{-2}$ -------------------							
Coating	Peat								
Uncoated	With	1.41	1.12	0.79	0.80	0.89	0.75	0.45	0.22
Uncoated	Without	3.20	1.19	0.50	0.29	2.24	0.58	0.15	1.22
Naturally	With	1.00	0.82	0.45	0.40	0.33	0.30	0.08	0.01
Naturally	Without	1.24	1.17	0.68	0.34	0.33	0.64	0.32	0.04
Artificially	With	0.51	0.25	0.17	0.15	0.20	0.11	0.08	0.05
Artificially	Without	0.26	0.16	0.10	0.15	0.15	0.09	0.09	0.08
$LSD_{0.05}$		---	---	---	---	0.47	---	0.21	0.24
Significance of the interaction		0.10	0.52	0.07	0.08	0.00	0.08	0.00	0.00

Table 4-9 Influence of peat and coating main effects on K uptake by bermudagrass as a function of time after planting phase I 2000.

Main effects	Days after planting				
	29	43	58	71	Total
	------------------g m^{-2}---------------------				
Peat					
With	1.46a†	3.14a	2.31a	2.37a	9.28a
Without	0.82b	2.34b	1.47b	1.81b	6.45b
Sand coating					
Uncoated	0.13c	1.43b	0.96b	1.30c	3.83c
Naturally	2.00a	3.38a	2.51a	2.84a	10.72a
Artificially	1.29b	3.41a	2.20a	2.14b	9.04b

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test

Table 4-10 Influence of peat and coating main effects on P leached as a function of time after planting for fertilization applied 0, 30, 57 days after planting phase I 2000.

Main effects	Days after planting									
	7	14	21	28	35	49	56	70	Total Leached	
	------------------- g m^{-2} -------------------									%
Peat										
With	0.49a†	0.40‡	0.35‡	0.27‡	0.26‡	0.17a	0.20a	0.16‡	2.31a	21
Without	0.46a	0.25	0.10	0.10	0.17	0.10a	0.13b	0.14	1.46b	13
Sand Coating										
Uncoated	0.43b	0.29	0.18	0.13	0.23	0.12b	0.12b	0.12	1.63b	14
Naturally	0.00c	0.02	0.02	0.02	0.02	0.01c	0.02c	0.01	0.11c	0.1
Artificially	0.99a	0.68	0.49	0.41	0.39	0.26a	0.37a	0.32	3.91a	35

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-11 Interaction of peat and coating main effects on P leached as a function of time after planting for fertilization applied 0, 30, and 57 days after planting phase I 2000.

Main effects		Days after planting							
		7	14	21	28	35	49	56	70
Interaction means		------------------- g m^{-2} -------------------							
Coating	Peat								
Uncoated	With	0.32	0.35	0.28	0.21	0.16	0.15	0.15	0.09
Uncoated	Without	0.54	0.22	0.09	0.05	0.29	0.10	0.08	0.15
Naturally	With	0.01	0.02	0.03	0.03	0.03	0.02	0.02	0.02
Naturally	Without	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.00
Artificially	With	1.15	0.84	0.76	0.56	0.57	0.33	0.43	0.39
Artificially	Without	0.82	0.52	0.21	0.25	0.22	0.20	0.31	0.25
$LSD_{0.05}$		---	0.17	0.17	0.08	0.11	---	---	0.07
Significance of the interaction		0.16	0.04	0.00	0.00	0.00	0.42	0.07	0.00

Table 4-12 Influence of peat and coating main effects on P uptake by bermudagrass as a function of time after planting phase I 2000.

Main Effects	Days after planting				
	29	43	58	71	Total
	------------------g m^{-2}--------------------				
Peat					
With	0.47a†	0.77a	0.63a	0.47a	2.33a
Without	0.26b	0.54b	0.42b	0.32b	1.54b
Sand Coating					
Uncoated	0.06b	0.41b	0.36c	0.29a	1.12c
Naturally	0.50a	0.55b	0.52b	0.45a	2.02b
Artificially	0.53a	1.01a	0.69a	0.44a	2.67a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-13 Influence of peat and coating main effects on water use efficiency phase I 2000.

	Date		
Main effects	3 - 16 Aug	17 Aug - 14 Sept	15 Sept - 12 Oct
	---------- mg tissue mL $water^{-1}$ ----------		
Peat			
With	2.47a†	2.36a	3.23a
Without	1.38b	1.76b	2.24b
Sand coating			
Uncoated	1.62b	1.00c	2.37a
Naturally	2.70a	2.26b	2.57a
Artificially	1.45b	2.94a	3.24a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

‡Comparisons among main effects (Peat and Sand Coating) are not made due to interactions between main effects.

Glasshouse Study: Phase II Year 2001

In 2001, Phase II was conducted to evaluate the effect of sand grain coatings and peat during a period following establishment. Data collected during phase II includes clipping production, and P and K leaching and uptake. In addition, data related to moisture relations, such as days until wilt and water use efficiency, were also collected.

Clipping Yield

The peat treatments only increased clipping yield for the first harvest period. While the inclusion of peat did not increase clipping yield during the following three harvest periods, peat did increase total clipping yield 16 % when summed over the four harvest periods. Brown et al. (2000) also observed an increase in total clipping yield production with peat in an established turfgrass system.

The presence of sand grain coatings increased clipping yield during each of the four harvest periods (Table 4-14). Artificially-coated sand produced more clipping yield than naturally-coated sand the last three harvest periods. Total clipping yield production from the artificially-coated sand was 15 % greater than naturally-coated sand and a 160 % increase over that of uncoated sand. It is unclear in previous studies (Brown et al., 2000) whether or not an increase in total clipping yield production was observed in the presence of sand grain coatings because of the statistical analysis conducted.

K Leached

Sand grain coatings influenced K leaching (Table 4-15). Less K leached from artificial- and naturally-coated sands than from uncoated sand during the 349 to 371 DAP period. Furthermore, at 363 DAP, less K leaching was observed with artificial coatings

than natural coatings. This same effect was also observed 381 DAP following K application at 371 DAP. Because an interaction between coating and peat occurred 375, 397, and 405 DAP statistical separation of main-effect means was not conducted. The interaction at 375 DAP resulted from a 57 % reduction of K leaching in the uncoated sand with peat versus the uncoated sand without peat, whereas, since there was little K loss in the coated sands, the influence of peat was less pronounced. The beneficial influence of peat was not permanent, as evidenced by the 397 and 405 DAP interactions in which greater K loss occurred from the uncoated sand with peat treatment relative to the uncoated sand and little K leached from the coated sands with or without peat.

Sand grain coatings reduced total K leached (Table 4-15). In addition, artificial coatings reduced K leaching by 35 % versus naturally-coated sand and 62 % relative to uncoated sand. Greater than 50 % of the applied K was leached from the uncoated sand treatments. Peat did not have an effect on total K leached.

K Uptake

Peat improved K uptake 355 DAP (Table 4-17). This improvement did not occur, however, as a result of increased K tissue concentration but as a result of increased clipping yield from the peat treatments observed only on that date (Table A-3). Peat did not increase K uptake during the three final harvest periods, but total K uptake was greater with the inclusion of peat (Table 4-17).

The presence of sand grain coatings increased K uptake relative to uncoated sand on all four harvest dates (Table 4-17). In addition, at 370, 381, and 397 DAP K uptake from artificially-coated sand was greater than naturally-coated sand by 30, 40, and 25 %

respectively. Potassium tissue concentrations were greater in naturally-coated sand than uncoated sand 355 and 397 DAP (Table A-3). However, differences in K tissue concentrations were not observed between naturally-coated sand and uncoated sand 370 and 381 DAP (Table A-3). Artificially-coated sand had greater K concentrations than uncoated sand at every harvest period. Furthermore, artificially-coated sand treatments had greater K tissue concentrations than naturally-coated sand 381 and 397 DAP.

Total K uptake was increased by both coatings and peat (Table 4-17). Artificially-coated sand increased total K uptake by 25% over naturally-coated sand and 210% over that of uncoated sand.

P Leached

Peat reduced P leaching 349 and 356 DAP (Table 4-18), but peat did not affect P leaching during any of the remaining four leaching events.

Phosphorus leaching was influenced by the presence of coatings (Table 4-18). As observed for the grow-in phase in 2000, more P was leached from artificially-coated sand than from uncoated and naturally-coated sand. The least amount of P loss occurred from the naturally-coated sand treatments. Naturally-coated sand reduced P leached by an average of 94% relative to uncoated sand during the first six leachate events. Comparisons among main effects (peat and sand coating) were not made due to interactions between the main effects 397 and 405 DAP (Table 4-19). Increased P leaching from uncoated sand with peat relative to uncoated sand without peat, in contrast to no effect of peat on P leaching from naturally- and artificially-coated sand, caused the interaction among main effects to occur at those times (Table 4-19).

Less total P was leached from naturally-coated sand than from uncoated and artificially-coated sand. Naturally-coated sand reduced total P leached by 92 and 98% relative to uncoated and artificially-coated sand.

As observed in Phase I, peat enhanced total P loss. Treatments with peat lost 37 % more total P than treatments without peat.

P Uptake

Peat did not affect P uptake (Table 4-20), nor did it affect P tissue concentration (Appendix). In Phase I, peat increased total P uptake (Table 4-12), however, peat did not affect total P uptake in Phase II (Table 4-20).

The presence of sand grain coatings increased P uptake relative to uncoated sand (Table 4-20). At all harvest periods, P uptake was greatest from the artificially-coated sand treatments. At 355, 370, and 397 DAP increased P uptake from artificially-coated sand can be attributed to not only increased clipping yield from the artificially-coated sand treatments but also to increased P tissue concentrations (Table A-4). Only at 381 DAP were artificially-coated and uncoated P tissue concentrations the same. In contrast, increased P uptake from naturally-coated sand relative to uncoated sand can only be attributed to greater clipping production from naturally-coated sand treatments, since naturally-coated sand P tissue concentrations were less than those of uncoated sand (Table A-4). This observation was also made in phase I (Table 4-12, A-2).

While Brown et al. (2000) in an established turfgrass study did not observe an increase in P uptake from naturally-coated sand, in the current established turfgrass study,

total P uptake was increased by the presence of sand grain coatings. Artificially-coated sand increased total P uptake by 67 and 195 % relative to naturally-coated and uncoated sand.

Days Until Wilt

Because of greater available water (Table 4-2), the presence of sand grain coatings and peat increased the number of days between cessation of irrigation and wilting (Table 4-21). There was no difference between artificially- and naturally-coated sand. The presence of peat in the root zone mix delayed wilting symptoms of drought stress four days beyond those treatments without peat.

Water Use Efficiency

Overall water use efficiency decreased relative to Phase I 2000 values (Table 4-22). The relative decrease in water use efficiency observed in Phase II 2001 can likely be attributed to the method of evaluation in which applications of water ceased, thereby creating moisture stressed conditions which in turn reduced overall dry matter production.

Regardless of experimental technique, similar trends were observed in Phase II 2001. Comparisons among main effects (peat and sand coating) were not made due to interactions between main effects (Table 4-22). Peat increased water use efficiency of uncoated sand, but did not influence water use efficiency of artificially- and naturally-coated sand. The presence of sand grain coatings increased water use efficiency relative to uncoated sand.

Summary: Phase II

The purpose of Phase II was to continue the evaluation of sand grain coatings and peat and make observations relative to changes in root zone performance during a period of well-established actively growing turfgrass.

In Phase II, the presence of sand grain coatings impacted measures of root zone performance. Sand grain coatings increased clipping production as was previously observed in Phase I. As in Phase I, sand grain coatings reduced K leaching and increased K uptake. Both artificially- and naturally-coated sand increased tissue K concentrations. Naturally-coated sand, however, was less consistent, relative to uncoated sand, in increasing tissue K concentrations in Phase II as compared to Phase I. As observed in Phase I, naturally-coated sand reduced P leached. The emathlite clay and polymer matrix associated with artificially-coated sand coatings continued to supply leachable P from artificially-coated sand treatments. Sand grain coatings continued to increase P uptake as observed in Phase I. It should be noted, however, that the increase in P uptake associated with naturally-coated sand can only be attributed to increased clipping production since tissue P concentrations were less than or equal to that of uncoated sand. Sand grain coatings increased the number of days between cessation of irrigation and wilting. Finally, sand grain coatings clearly increased water use efficiency.

The influence of peat in Phase II remained similar to that of Phase I. Peat only increased clipping production in a statistically-significant manner early in the data collection period. Peat did, however, increase total clipping production in Phase II, as was observed in Phase I. Peat continued to improve the K retention characteristics of

uncoated sand as was demonstrated by the reduction in K leaching, relative to uncoated sand without peat, in those leaching events following K fertilization. The beneficial influence of peat on K uptake appears to have diminished, with peat only increasing total K uptake. In Phase I peat increased K uptake at all sampling dates, however, no measurable difference in K uptake was observed in the individual sampling periods. In phase I, peat did not consistently increase tissue K concentration, and at no time in Phase II did peat increase tissue K concentration. Therefore, any increase in K fertilization efficiency can only be related to increased dry matter production. Peat continued to increase P leached. Unlike Phase I, in Phase II peat did not increase tissue P concentration and overall P uptake. Peat increased the number of days between cessation of irrigation and wilting. Finally, peat improved the water use efficiency of uncoated sand to that of the coated sands.

Table 4-14 Influence of peat and coating main effects on clipping production of bermudagrass as a function of time after planting phase II 2001.

	Days after planting				
Main effects	355	370	381	397	Total
	g m^{-2}				
Peat					
With	190a†	155a	86a	118a	501a
Without	142b	143a	80a	95a	430b
Sand coating					
Uncoated	78b	74c	46c	40c	238c
Naturally	206a	167b	91b	75b	538b
Artificially	215a	207a	112a	86a	620a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-15 Influence of peat and coating main effects on K leached as a function of time after planting, for K fertilization 343 and 371 days after planting, phase II 2001.

Main effects	Days after planting								
	349	356	363	371	375	381	397	405	Total
	------------------ $g\ m^{-2}$ ------------------								
Peat									
With	0.71a†	1.26b	1.21a	0.87a	0.74‡	0.39a	0.96‡	0.57‡	7.44a
Without	1.21a	1.95a	1.24a	0.67b	1.27	0.44a	0.57	0.32	8.46a
Sand coating									
Uncoated	1.70a	2.40a	1.85a	1.23a	1.95‡	1.70a	1.08‡	0.71‡	12.6a
Naturally	0.37b	1.37b	1.23b	0.57b	0.48	1.23b	0.82	0.35	6.43b
Artificially	0.80b	1.05b	0.58c	0.50b	0.59	0.58c	0.39	0.28	4.79b

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

‡Comparisons among main effects (Peat and Sand Coating) are not made due to interactions between main effects.

Table 4-16 An analysis of the peat and coating interaction on K leached as a function of time after planting, for K fertilization 343 and 371 days after planting 2001.

		Days after planting							
		349	356	363	371	375	381	397	405
Interaction means		---------------- $g\ m^{-2}$ ----------------							
Coating	Peat								
Uncoated	With	1.19	1.81	2.18	1.45	1.18	1.79	1.53	1.01
Uncoated	Without	2.22	2.99	1.51	1.01	2.72	1.61	0.64	0.40
Naturally	With	0.38	1.14	0.94	0.70	0.51	0.98	0.97	0.42
Naturally	Without	0.36	1.59	1.52	0.44	0.46	1.48	0.67	0.28
Artificially	With	0.55	0.84	0.51	0.44	0.55	0.61	0.37	0.27
Artificially	Without	1.06	1.27	0.67	0.56	0.64	0.56	0.41	0.29
$LSD_{0.05}$		---	---	---	0.31	0.46	---	0.45	0.51
Significance of the Peat X Coating interaction		0.33	0.30	0.08	0.05	0.00	0.21	0.02	0.04

Table 4-17 Influence of peat and coating main effects on K uptake by bermudagrass as a function of time after planting phase II 2001.

Main effects	Days after planting				
	355	370	381	397	Total
	------------------g m^{-2}---------------------				
Peat					
With	3.53a†	2.94a	1.62a	1.37a	9.46a
Without	2.66b	2.69a	1.44a	1.23a	8.03b
Sand coating					
Uncoated	1.24b	1.26c	0.79c	0.68c	3.97c
Naturally	3.78a	3.12b	1.59b	1.43b	9.93b
Artificially	4.26a	4.06a	2.22a	1.79a	12.33a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-18 Influence of peat and coating main effects on P leached as a function of time after planting for fertilization applied 343 and 371 days after planting phase II 2001.

Main effects	Days after planting								
	349	356	363	371	375	381	397	405	Total
	----------				$g\ m^{-2}$				----------
Peat									
With	0.56b†	0.61b	0.68a	0.67a	0.77a	0.41a	0.46‡	0.40‡	2.31a
Without	0.96a	0.94a	0.68a	0.74a	0.75a	0.41a	0.35	0.32	1.46b
Sand Coating									
Uncoated	0.57b	0.58b	0.49b	0.41b	0.48b	0.36b	0.32‡	0.26‡	3.48b
Naturally	0.02c	0.04c	0.03c	0.04c	0.03c	0.03c	0.04	0.03	0.26c
Artificially	1.69a	1.70a	1.51a	1.67a	1.77a	0.86a	0.85	0.79	10.85a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

‡Comparisons among main effects (Peat and Sand Coating) are not made due to interactions between main effects.

Table 4-19 An analysis of the peat and coating interaction on P leached as a function of time after planting for fertilization applied 343 and 371 days after planting, phase II 2001.

Main effects		Days after planting							
		349	356	363	371	375	381	397	405
Interaction means		----------			$g\ m^{-2}$				----------
Coating	Peat								
Uncoated	With	0.22	0.38	0.53	0.47	0.43	0.37	0.42	0.34
Uncoated	Without	0.92	0.79	0.46	0.35	0.54	0.35	0.22	0.18
Naturally	With	0.02	0.04	0.04	0.04	0.04	0.03	0.04	0.04
Naturally	Without	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.03
Artificially	With	1.43	1.41	1.46	1.51	1.84	0.84	0.91	0.82
Artificially	Without	1.95	2.00	1.57	1.83	1.70	0.87	0.80	0.76
$LSD_{0.05}$		---	---	---	---	---	---	0.11	0.09
Significance of the Peat X Coating interaction		0.16	0.11	0.81	0.19	0.31	0.97	0.04	0.04

Table 4-20 Influence of peat and coating main effects on P uptake by bermudagrass as a function of time after planting phase II 2001.

Main effects	Days after planting				
	355	370	381	397	Total
	------------------		$g\ m^{-2}$	--------------------	
Peat					
With	1.10a†	0.86a	0.44a	0.38a	2.79a
Without	0.86a	0.83a	0.40a	0.37a	2.47a
Sand coating					
Uncoated	0.48c	0.42c	0.26c	0.22c	1.38c
Naturally	0.95b	0.76b	0.36b	0.36b	2.44b
Artificially	1.52a	1.36a	0.65a	0.54a	4.07a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-21 Influence of peat and coating main effects on the number of days until wilt phase II 2001.

Main effects	Days until wilt
Peat	
With	15a†
Without	11b
Sand coating	
Uncoated	10b
Naturally	15a
Artificially	14a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-22 Influence of coating and peat on water use efficiency phase II 2001.

Coating	Peat	Water use efficiency
		- mg tissue ml water^{-1} -
Uncoated	With	0.82
Uncoated	Without	0.37
Naturally-coated	With	0.77
Naturally-coated	Without	0.80
Artificially-coated	With	0.84
Artificially-coated	Without	1.17
$LSD_{0.05}$		0.35
Significance of the Peat X Coating interaction		0.01

Glasshouse Study: Phase III Year 2002

Phase III began two years following Phase I 2000 (establishment) and one year after Phase II 2001 (maintenance) in order to further evaluate the long-term effects of sand grain coating and peat on root zone behavior. The same variables were investigated in Phase III 2002 as in Phase II 2001.

Clipping Production

In 2002, peat and coating influenced clipping production. Since an interaction between peat and sand coating occurred 699 DAP, comparisons among the main effects are not made (Table 4-23). The interaction resulted because peat increased clipping production 41% for the uncoated sand, but did not affect production in naturally- and artificially-coated sand (Table 4-24). In addition, the presence of peat increased clipping production of uncoated sand to a quantity equal to that of artificially-coated sand with or without peat. Artificially-coated sand increased clipping production 10% over naturally-coated sand and 27% over uncoated sand 715 DAP. There was no effect of peat and no difference between uncoated and naturally-coated sand 715 DAP. Because the same interaction observed 699 DAP occurred 729 DAP, comparisons among the main effects are not made. Again, peat increased clipping production 34 % for the uncoated sand and did not affect naturally- and artificially-coated sand. Peat and coating affected clipping production 746 DAP. Peat increased clipping production 27%. Artificially-coated sand also increased clipping production. As observed 715 DAP, there was no difference between uncoated and naturally-coated sand 746 DAP.

In Phase I and Phase II, peat clearly increased clipping production. However, in Phase III the effect of peat on clipping production was less evident. For total clipping production, comparisons among main effects (peat and sand coating) are not made due to interactions between main effects. As observed on sampling dates 699 and 729 DAP, peat increased total clipping production 37% for the uncoated sand and did not affect that of naturally- and artificially-coated sand. Consequently, at this point in the study, only uncoated sand was benefitting from peat in terms of clipping production.

K Leached

Peat and coating did not affect K leaching as much as in the establishment (Phase I) and first maintenance period (Phase II) (Table 4-25). Potassium was applied 638 DAP with four leaching events following application. There was no effect of peat or coating on K leached 692, 699, 704, and 714 DAP (Table 4-25). A lack of significance may have occurred because of high variability associated with the data over that period of time (Table 4-26). Over a similar period early in Phase II, sand grain coatings decreased K leaching (Table 4-16). When K was reapplied 715 DAP an effect of coating on K leached was observed 718 DAP with less K leached from artificially-coated sand than uncoated and naturally-coated sand. During this period of data collection (715 - 761 DAP), less variability in the data were observed (Table 4-26). There was no difference between uncoated sand naturally-coated sand 718 DAP. An interaction between peat and coating was observed 727 and 739 DAP. Peat decreased K leaching from uncoated sand 62% 727 DAP and 68% 739 DAP. Peat did not affect K leached from naturally- and artificially-coated sand 727 and 739 DAP. Less K leached from naturally-coated sand

without peat than uncoated sand without peat 727 and 739 DAP demonstrating the ability of natural sand grain coatings to continue reducing K leaching two years after establishment. Both natural and artificial coatings reduced K leached 761 DAP. To this point, the ability of sand grain coatings to reduce K leached endured.

In Phase I (Table 4-7) and Phase II (Table 4-15), naturally- and artificially-coated sand reduced total K leached. For total K leached in Phase III, comparisons among main effects were not made due to interactions between the main effects peat and sand coating. The interaction occurred because peat reduced total K leached from uncoated sand, but did not affect total K leached from naturally- and artificially-coated sand (Table 4-25, 4-26). In addition, peat reduced total K leached from uncoated sand to levels similar to naturally- and artificially-coated sand with and without peat. However, in the absence of peat, naturally- and artificially-coated sand reduced total K leached by 58 % and 66 % relative to that of uncoated sand without peat (Table 4-26).

K Uptake

The presence of sand grain coatings increased K uptake throughout phase III (Table 4-27, 4-28). Artificially- and naturally-coated sand increased K uptake relative to uncoated sand 699 DAP. Artificially- and naturally-coated sand did not, however, increase K tissue concentration (Table A-5). There was no difference between artificially- and naturally-coated sand (Table A-5). During Phase I and Phase II, the presence of natural and artificial coatings increased tissue K concentration (Table A-1, A-3).

At 715 DAP, artificially- and naturally-coated sand increased K uptake over that of uncoated sand. Again, there was no difference between artificially- and naturally sand, and no difference in K tissue concentration among the sand types (Table A-5, A-6). A peat by coating interaction was detected 729 DAP (Table 4-28). The interaction was the result of increased K uptake by uncoated sand in the presence of peat whereas peat did not improve K uptake from artificially- and naturally-coated sand. Artificially- and naturally-coated sand increased K uptake over that of uncoated sand 746 DAP. In addition, artificially-coated sand had greater K tissue concentration than uncoated sand but not naturally-coated sand (Table A-5). There was no difference in K tissue concentration between naturally-coated and uncoated sand (Table A-5).

Sand grain coatings increased total K uptake (Table 4-27). Artificially-coated sand increased total K uptake 41% over that of uncoated sand. There was no difference between artificially- and naturally-coated sand.

The effect of peat on K uptake was inconsistent (Table 4-27). Peat did not improve K uptake 699 DAP. Peat did, however, increase K uptake 715 DAP. In addition, peat increased K tissue concentration 715 DAP (Table A-5). Because of an interaction 729 DAP there was no comparison of main effects. The interaction was the result of positive influence of peat on K uptake from uncoated sand (Table 4-28). The presence of peat did not influence K uptake from artificially- and naturally-coated sand. At 746 DAP peat increased K uptake. Unlike 715 DAP, there was no increase in K concentration in the presence of peat 746 DAP. Peat increased total K uptake 16% (4-27).

P Leached

In Phase III, sand grain coating influenced P leaching (Table 4-29). As in the earlier study periods, greater quantities of P leached from artificially-coated sand than from uncoated and naturally-coated sand throughout 2002. There was no difference between uncoated and naturally-coated sand 692 and 699 DAP. The lack of significance between uncoated and naturally-coated sand 692 and 699 DAP was likely due to a high degree of variability associated with the data (Table 4-29) . The variability may be due to difficulty in measuring the smaller quantities of P leached in Phase III. Less P, however, did leach from naturally-coated sand than uncoated sand 704 DAP. There was no difference between uncoated and naturally-coated sand 714 DAP, presumably because most mobile P applied at 683 DAP had leached through the system.

Phosphorus was reapplied 715 DAP and similar differences among coatings which had occurred in 2000 and 2001 repeated themselves the remaining four leaching events. The interaction occurring 739 DAP resulted from 63 % less P leached from uncoated sand with peat than uncoated sand without peat, but no influence of peat on P leached from naturally- and artificially-coated sand. Peat did not affect P leached through the first six leaching events of 2002. Peat did, however, reduce P leached 761 DAP. In contrast, at no time did peat reduce P leached during Phase I and Phase II. Moreover, peat increased P leached in Phase I 31% and Phase II 31%. This change in the P leaching characteristics associated with peat may signal a depletion of P available for mineralization and an end to peat as a source of leachable P.

The potential for peat to now serve as a direct source for P appears minimal. Rock et al. (1984) concluded in laboratory studies that peat was incapable of removing substantial P. Peats low in Al and Fe exhibit low P retention capabilities (Nichols and Boelter, 1982).

Peat, however, may now be serving as an indirect source of P removal by increasing the microbial population of those sands containing peat. Studies have shown that greater bacterial populations exist in sand peat mixtures versus sand only (USGA, 2000). Phosphorus immobilization in soils by microbes can occur when organic residues low in P but high in carbon and other nutrients exist (Brady and Weil, 2000). Phosphorus removal associated with peat is attributed to microbial assimilation (Nichols and Boelter, 1982). Rannikko and Hartikainen (1981) attributed their 9% removal of P to microbial immobilization in sphagnum peat.

Only sand grain coating affected total P leached in 2002. Naturally-coated sand reduced total P leached 92% relative to uncoated sand and 97% relative to artificially-coated sand. In Phase I and Phase II peat increased total P leached. For the first time, during Phase III, peat did not affect total P leached, perhaps for reason stated above.

<u>P Uptake</u>

In general, P uptake in Phase III was less than that of Phase II. While dry matter production did not dramatically decrease, tissue P concentration generally decreased for both peat and coating in 2002 (Table A-7).

The effect of sand grain coatings on P uptake varied (Table 4-30). The presence of sand grain coatings did not increase P uptake until 715 DAP. However, only

artificially-coated sand increased P uptake 715 DAP. There was no difference between naturally-coated and uncoated sand. There was no difference in P tissue concentration among the sand types (Table a-7). A comparison of main effects was not conducted 729 DAP because of an interaction (Table 4-31). The interaction occurred because uncoated sand with peat had more P uptake than uncoated sand without peat, whereas peat did not influence P uptake from artificially- and naturally-coated sand. Artificially-coated sand without peat did improve P uptake relative to uncoated sand without peat 729 DAP. Artificially-coated sand also increased P uptake over that of uncoated sand 746 DAP. There was no difference between uncoated and naturally-coated sand 746 DAP. There was no difference in P tissue concentrations 746 DAP (Table A-7).

Total P uptake was only increased by artificially-coated sand (Table 4-30). Artificially-coated sand increased total P uptake 35% relative uncoated and 20% relative to naturally-coated sand. In Phase II, P uptake from naturally-coated sand was greater than that of uncoated sand. However, in Phase III there was no difference in total P uptake between uncoated and naturally-coated sand and no difference tissue P concentration (Table A-7).

Peat had a minimal effects on P uptake (Table 4-30). An increase in P uptake due to the presence of peat was not detected at individual harvest dates. Furthermore, peat did not increase tissue P concentration (Table A-7).

Peat only influenced uncoated sand. A peat by coating interaction occurred at 729 DAP in which peat improved P uptake by bermudagrass in uncoated sand (Table 4-31). Furthermore, the addition of peat to uncoated sand improved P uptake from uncoated sand to that of artificially- and naturally-coated sand with or without peat.

Total P uptake was improved by peat (Table 4-30). Peat had not improved total P uptake in Phase II.

Days Until Wilt and Water Use Efficiency

In Phase III, the number of days to wilt and water use efficiency increased relative to Phase II. Both trials were conducted during the same time of year. Perhaps a more mature turf with a greater accumulation of thatch, adding to moisture retention, and root mass was better able to delay wilt and more efficiently use moisture.

Peat and artificially-coated sand increased the number of days between cessation of irrigation and wilting (Table 4-32). While artificially-coated sand did delay wilt, peat appeared to have a greater effect on wilt. Peat delayed wilt by an average of five days whereas artificially-coated sand reduced time to wilt by only two. Unlike in 2001, naturally-coated sand was not effective in delaying wilting.

Sand grain coating increased water use efficiency. Artificially- and naturally-coated sand had greater water use efficiency than uncoated sand. There was no detectable difference in water use efficiency in treatments with and without peat in 2002. In phase II, peat had only increased the water use efficiency of uncoated sand (Table 4-21).

Cation Exchange Capacity

The cation exchange capacity of root-zone materials, determined at the conclusion of the glasshouse study, was affected by the coating and peat variables (Table 4-33). The CEC of coated sands were greater than uncoated sand. Of the coated sands, CEC of artificially-coated sand was greater than naturally-coated sand. The incorporation of peat increased CEC for uncoated and naturally-coated sand. Interestingly, the CEC of artificially-coated sand with peat was less than that of artificially-coated sand without peat.

Because uncoated and coated sand with peat mixtures were not measured prior to Phase I comparisons in CEC can only be made on the uncoated and coated sands without peat.

The CEC of uncoated sand and coated sands generally changed little (Table 4-33) relative to CEC values determined prior to Phase I (Table 4-3). Despite three years of potential organic matter addition from thatch and root growth, the CEC of uncoated sand did not increase from 0.0 $cmol_c\ kg^{-1}$. The CEC of naturally-coated sand generally increased, but the increase could simply be the result of variation during CEC determination. The CEC of artificially-coated sand generally decreased relative to Phase I perhaps because of clay loss or experimental error.

Selected Chemical/Physical Properties of Root-Zone Materials upon Completion of Phase III

An interaction of coating and peat occurred for pH (Table 4-34). The interaction occurred because the presence of peat only decreased the pH of uncoated sand and not

that of naturally- and artificially-coated sand (Table 4-35). Sphagnum peat, an acidic peat source, may have had less impact on naturally- and artificially-coated sand because of their already low pH status. In addition, poorly buffered uncoated sand is perhaps more susceptible to the influence of amendment properties.

An interaction of coating and peat occurred with acetic acid-extractable P (Pa) (Table 4-34). Artificially-coated sand both with and without peat had greater Pa than uncoated and naturally-coated sand with and without peat (Table 4-35). Brown et al. (2000) observed an increase in Mehlich I extractable P from naturally-coated sand relative to uncoated sand in both a grow-in study and an established study. A difference, however, could not be detected between uncoated and naturally-coated sand when data where analyzed with artificially-coated sand included in the analysis. When analyzed without artificially-coated sand, a difference between naturally-coated and uncoated sand was detected ($P>0.0005$). Using this method of data analysis, naturally-coated sand increased soil-test Pa.

The presence of sand grain coatings increased water soluble P (Pw)(Table 4-34 4-35). Artificially-coated sand had greater Pw at the end of the study than naturally-coated sand. In addition, there was greater Pw from naturally-coated than uncoated sand.

Peat influenced the quantity of Pw (Table 4-34). Sand with peat had more Pw than sand without peat. This finding helps to support the observation that peat increases P leached (Table 4-10, 4-18).

The presence of sand grain coatings increased extractable K (Table 4-34). Artificially-coated sand had the highest extractable K. Naturally-coated sand had greater

extractable K than uncoated sand. Peat did not increase extractable K content (Table 4-34). Along with K leached data (4-7, 4-15, 4-25) these finding suggest that CEC associated with sand grain coatings are more influential than peat with regard to K retention.

Summary: Phase III

The influence of sand grain coatings continued in 2002. Sand grain coatings improved clipping production as was observed in Phases I and II. In Phase III, sand grain coatings continued to reduce K leached, but the ability of the coatings to reduce K leaching appears to have diminished. Naturally-coated sand continued to reduce P leaching in comparison to uncoated sand, while more P continued to leach from artificially-coated sand. While naturally-coated sand decreased P leaching, it did not increase P uptake. As in Phase II, artificially-coated sand increased the number of days between cessation of irrigation and wilting. Naturally-coated sand did not decrease wilting potential with respect to uncoated sand. Sand grain coatings did increase water use efficiency as previously observed in phases I and II. The presence of sand grain coatings increased CEC to levels greater than that of uncoated sand. Artificially-coated sand had greater soil-test K, Pa, and Pw than naturally-coated and uncoated sand. Naturally-coated sand had greater soil-test K, Pa, and Pw than uncoated sand.

Peat continued to exhibit some of the same characteristics demonstrated in Phases I and II. Peat only improved dry matter production of uncoated sand in Phase III. In addition, peat only reduced K leached from uncoated sand. Peat began to show signs of improved P retention during the later stages of Phase III, perhaps due to less available P

for mineralization and increased P assimilation by the microbial biomass. As in Phase II, peat increased the number of days between cessation of irrigation and wilting. An increase in water use efficiency was not detected during Phase III. Peat increased the CEC of uncoated and naturally-coated sand, however, the presence of peat decreased the CEC of artificially-coated sand. Peat only decreased soil-test pH of uncoated sand. Peat increased Pw, and had no effect on soil K.

Table 4-23 Influence of peat and coating main effects on clipping production of bermudagrass as a function of time after planting phase III 2002.

	Days after planting				
Main effects	699	715	729	746	Total
	-------------------	-------------------	g m^{-2}	-------------------	-------------------
Peat					
With	149†	137a‡	79†	123a	489†
Without	140	126a	74	97b	438
Sand coating					
Uncoated	127	115b	66	88b	397
Naturally	146	133ab	80	107b	465
Artificially	161	146a	85	135a	527

†Comparisons among main effects (Peat and Sand Coating) are not made due to interactions between main effects.

‡Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-24 An analysis of the peat and coating interaction on clipping production of bermudagrass as a function of time after planting phase III 2002.

		Days after planting				
Main effects		699	715	729	746	Total
Interaction Means		-------------------	-------------------	g m^{-2}	-------------------	-------------------
Coating	Peat					
Uncoated	With	149	129	76	105	459
Uncoated	Without	106	102	57	71	336
Naturally	With	141	140	82	123	487
Naturally	Without	150	126	77	90	444
Artificially	With	157	142	80	142	521
Artificially	Without	165	150	90	129	534
$LSD_{0.05}$		20	---	12	---	57
Significance of the Peat X Coating Interaction		0.00	0.16	0.01	0.52	0.01

Table 4-25 Influence of peat and coating main effects on K leached as a function of time after planting for fertilization applied 682, 715, and 747 days after planting phase III 2002.

Main effects	Days after planting								
	692	699	704	714	718	727	739	761	Total
	------------------- $g\ m^{-2}$ -------------------								
Peat									
With	0.69a†	0.17a	0.15a	0.10a	0.18a	0.17‡	0.11‡	0.51a	1.76‡
Without	0.31a	0.18a	0.11a	0.06a	0.20a	0.27	0.18	0.51a	2.21
Sand Coating									
Uncoated	0.38a	0.20a	0.14a	0.07a	0.27a	0.38‡	0.78‡	0.72a	2.95
Naturally	0.20a	0.14a	0.12a	0.10a	0.20a	0.20	0.34	0.40b	1.71
Artificially	0.21a	0.18a	0.12a	0.06a	0.11b	0.08	0.12	0.40b	1.30

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

‡Comparisons among main effects (Peat and Sand Coating) are not made due to interactions between main effects.

Table 4-26 An analysis of the peat and coating interaction on K leached as a function of time after planting for fertilization applied 682, 715, and 747 days after planting phase III 2002.

Main effects		Days after planting								
		692	699	704	714	718	727	739	761	Total
Interaction means		------------------- $g\ m^{-2}$ -------------------								
Coating	Peat									
Uncoated	With	0.39	0.19	0.15	0.07	0.20	0.21	0.38	0.53	2.13
Uncoated	Without	0.38	0.22	0.12	0.06	0.36	0.55	1.18	0.92	3.77
Naturally	With	0.13	0.16	0.16	0.14	0.24	0.21	0.29	0.53	1.86
Naturally	Without	0.28	0.13	0.08	0.05	0.16	0.19	0.39	0.27	1.56
Artificially	With	0.15	0.17	0.13	0.06	0.11	0.08	0.12	0.47	1.30
Artificially	Without	0.27	0.19	0.12	0.08	0.11	0.08	0.12	0.33	1.30
$LSD_{0.05}$		---	---	---	---	---	0.16	0.37	---	0.96
C.V. (%)		80	58	63	78	43	47	59	52	32
Significance of the interaction		0.74	0.83	0.67	0.25	0.07	0.01	0.01	0.07	0.02

Table 4-27 Influence of peat and coating main effects on K uptake by bermudagrass as a function of time after planting phase III 2002.

Main effects	Days after planting				
	699	715	729	746	Total
	-g m^{-2}-				
Peat					
With	1.76a†	2.25a	1.53‡	2.25a	7.48a
Without	1.59a	1.87b	1.35	1.87b	6.47b
Sand coating					
Uncoated	1.42b	1.66b	1.28	1.32c	5.68b
Naturally	1.76a	2.16a	1.50	1.81b	7.24a
Artificially	1.83a	2.36a	1.55	2.26a	8.00a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

‡Comparisons among main effects (Peat and Sand Coating) are not made due to interactions between main effects.

Table 4-28 Interaction of coating and peat on K uptake by bermudagrass phase III 2002.

Coating	Peat	Days after planting
		729
		- g m^{-2} -
Uncoated	with	1.56
Uncoated	without	0.99
Naturally-coated	with	1.61
Naturally-coated	without	1.39
Artificially-coated	with	1.43
Artificially-coated	without	1.67
$LSD_{0.05}$		0.40
Significance of the Peat X Coating interaction		0.02

Table 4-29 Influence of peat and coating main effects on P leached as a function of time after planting for fertilization applied 682, 715, and 747 days after planting phase III 2002.

Main effects	Days after planting								
	692	699	704	714	718	727	739	761	Total
	$g\ m^{-2}$								
Peat									
With	0.12a†	0.12a	0.14a	0.12a	0.14a	0.09a	0.11‡	0.11b	0.95a
Without	0.13a	0.14a	0.13a	0.13a	0.16a	0.13a	0.18	0.19a	1.20a
Sand Coating									
Uncoated	0.10b	0.08b	0.10b	0.06b	0.12b	0.12b	0.19‡	0.15b	0.92b
Naturally	0.01b	0.01b	0.01c	0.01b	0.01c	0.01c	0.01	0.01c	0.07c
Artificially	0.26a	0.31a	0.31a	0.29a	0.32a	0.21a	0.24	0.30a	2.24a
C.V. (%)	85	94	66	55	46	50	30	55	55

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

‡Comparisons among main effects (Peat and Sand Coating) are not made due to interactions between main effects.

Table 4-30 Influence of peat and coating main effects on P uptake by bermudagrass as a function of time after planting phase III 2002.

Main effects	Days after planting				
	699	715	729	746	Total
	----------------	-----------------	-g m^{-2}-	-----------------	----------------
Peat					
With	0.36a†	0.44a	0.31‡	0.44a	1.55a
Without	0.34a	0.39a	0.28	0.39a	1.39b
Sand coating					
Uncoated	0.32a	0.35b	0.27	0.35b	1.27b
Naturally	0.32a	0.42ab	0.29	0.42ab	1.43b
Artificially	0.38a	0.47a	0.33	0.47a	1.71a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

‡Comparisons among main effects (Peat and Sand Coating) are not made due to interactions between main effects.

Table 4-31 Interaction of coating and peat on P uptake by bermudagrass phase III 2002.

Coating	Peat	Days after planting
		729
		- g m^{-2} -
Uncoated	with	0.32
Uncoated	without	0.22
Naturally-coated	with	0.31
Naturally-coated	without	0.27
Artificially-coated	with	0.31
Artificially-coated	without	0.36
$LSD_{0.05}$		0.07
Significance of the Peat X Coating interaction		0.02

Table 4-32 Influence of peat and coating main effects on the number of days until wilting and water use efficiency 779 days after planting phase III 2002.

Main effects	Days until wilt	Water Use Efficiency
		- mg tissue ml water^{-1} -
Peat		
With	19a†	1.65a
Without	14b	1.43a
Sand coating		
Uncoated	16b	1.22b
Naturally	16b	1.62a
Artificially	18a	1.77a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-33 Effect of coating and peat on cation exchange capacity at the completion of glasshouse study phase III 2002.

Main Effects		Cation Exchange Capacity
Coating	Peat	- - - - - $cmol_c$ kg^{-1} - - - - -
Uncoated	With	1.4
Uncoated	Without	0.0
Naturally	With	6.5
Naturally	Without	4.8
Artificially	With	6.5
Artificially	Without	9.8
$LSD_{0.05}$		0.2
Significance of the Peat X Coating interaction		< 0.00

Table 4-34. Selected properties of materials at the completion of Phase III.

Main Effects	pH	Pa	Pw	K
		- - - - - - - - mg L^{-1} - - - - - - - -		
Peat				
With	4.3†	87.9†	12.1a	14.9a
Without	5.0	129.4	8.7b	18.6a
Sand Coating				
Uncoated	4.9	7.1	3.3c‡	5.8c
Naturally	4.3	44.8	8.7b	12.3b
Artificially	4.6	274.2	19.2a	32.0a

†Comparisons among main effects (Peat and Sand Coating) are not made due to interactions between main effects.

‡Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-35 Interaction of coating and peat on selected chemical properties at the completion of glasshouse study phase III 2002.

Main Effects		pH	Pa	Pw	K
Coating	Peat		- - - - - - - - - - mg L^{-1} - - - - - - - - -		
Uncoated	With	4.3	6.7	4.6	5.2
Uncoated	Without	5.5	7.5	2.1	6.5
Naturally	With	4.1	42.9	12.0	12.6
Naturally	Without	4.5	46.6	5.3	12.0
Artificially	With	4.4	214.2	19.8	26.8
Artificially	Without	4.8	334.1	18.6	37.1
$LSD_{0.05}$		0.4	71.9	---	---
Significance of the Peat X Coating interaction		0.02	0.03	0.14	0.06

Artificially-Coated Sand: A Rate Study

The previous glasshouse work, which for the artificially-coated treatment was conducted with 100% of root zone media being a coated sand demonstrated that the coated sand enhanced turfgrass growth and soil properties, relative to uncoated sand. The amendment rate study was conducted to identify a rate (less than 100 %) at which artificially-coated sand could be incorporated into a root zone and remain effective. Clay-coated sand rate was studied both with and without added peat (100 ml L-1).

An effect of the artificially-coated sand amendment was observed on all dates. In addition, an effect was observed at all rates of artificially-coated sand. The magnitude of improvement, however, varied with and without the presence of peat.

In the absence of peat, inclusion of artificially-coated sand greatly improved bermudagrass establishment (Fig 4-2). Measurable increases in establishment rate were already distinguishable at 10 DAP. The established turf area at 10 DAP of uncoated sand amended with artificially-coated sand was approximately 10 - 15% greater than uncoated alone. There were no differences in establishment rate above 12.5% artificially-coated sand. At 15 DAP uncoated sand amended with artificially-coated sand had 30 - 40% greater bermudagrass establishment than uncoated sand alone. There was no difference in artificially-coated sand rates above approximately 20% at 15 DAP. At 23 DAP artificially-coated sand had 86% bermudagrass establishment while uncoated sand alone had only 25% establishment. There was no difference above approximately a rate of 17% artificially-coated sand. Bermudagrass reached full establishment 30 DAP in the presence of as little as 12% artificially-coated sand. The turf planted on uncoated sand

alone had only reached 50% coverage 30 DAP. Beyond an artificially-coated sand rate of 12% sand there was no improvement in establishment 30 DAP.

The presence of artificially-coated sand also improved bermudagrass establishment in uncoated sand with peat (Fig. 4-3). The magnitude of improvement in establishment rate, however, was less than that observed in the absence of peat. Artificially-coated sand increased establishment rate 10 DAP. There was no increase in bermudagrass establishment above a rate of 20% artificially-coated sand. At 15 DAP the presence of artificially-coated sand continued to improve establishment rate. There was no difference in bermudagrass establishment above a rate of 32% artificially-coated sand 15 DAP. Bermudagrass growing in as little as 4% artificially-coated sand reached almost full establishment 23 DAP. There was no difference in artificially-coated sand rates above 8% 23 DAP. At 30 DAP bermudagrass reached 100% establishment in the presence of artificially-coated sand with no difference in establishment rate above 4 % artificially-coated sand.

The effect of artificially-coated sand varied in the presence and absence of peat. In the absence of peat, a lower rate of artificially-coated sand made a greater impact on establishment rate over the first 15 DAP. The presence of peat, with its ability to retain water and nutrients, diminished the effect of artificially-coated sand through 15 DAP. Interestingly, less artificially-coated sand was required to increase establishment rate through the final 15 days of establishment. Based on this study, incorporation of artificially-coated sand beyond a rate of 32% is unnecessary.

The rate of artificially-coated sand and presence of peat had an effect on most physical measures of the various mixes (Table 4-36). The only measure which peat did not influence was macropore space.

K_{sat} was affected by rate and peat (Table 4-36). A peat by rate interaction was not detected. However, it appears that at artificially-coated sand rates of 12.5% and 25% reduces K_{sat} in the presence of peat in the mix. The optimum rate of artificially-coated sand and peat, based on K_{sat}, appears to be at the 12.5% rate of artificially-coated sand.

Bulk density was affected by rate and peat (Table 4-36). There was no rate by peat interaction. Bulk density generally decreased with an increasing rate of artificially-coated sand. Furthermore, peat reduced bulk density.

Total pore space was influenced by rate and peat (Table 4-36). There was no rate by peat interaction. Total pore space generally increased with rate. Peat also increased total pore space.

Rate affected macropore space (Table 4-36). Peat did not affect macropore space nor was there a rate by peat interaction.

Rate and peat influenced micropore space (Table 4-36). As rate increased micropore space generally increased. There was very little difference between the 12.5% and 25% rates with and without peat. Peat increased micropore space across all rates of artificially-coated sand.

Water holding capacity (weight basis) was affected by rate and peat (Table 4-36). In addition, there was a rate by peat interaction. The highest water holding capacity was observed at the highest rate of artificially-coated sand with peat.

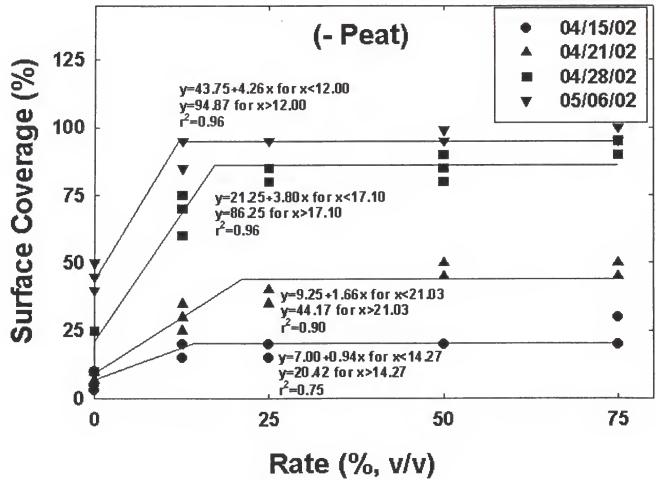

Fig 4-2. Effect of artificially-coated sand amendment to uncoated sand on bermudagrass establishment.

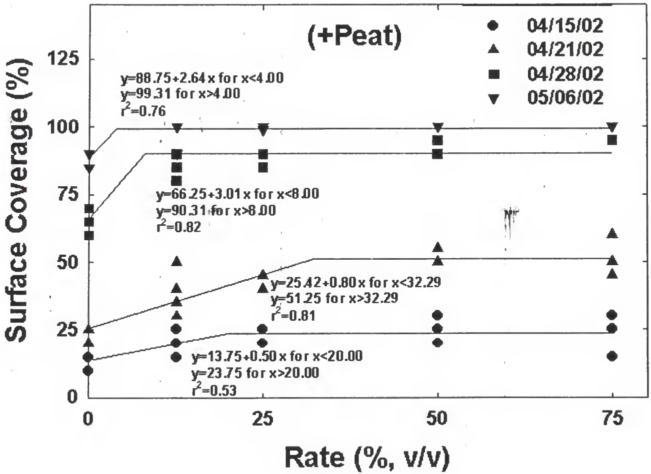

Fig 4-3. Effect of artificially-coated sand amendment to uncoated sand with peat on bermudagrass establishment.

Table 4-36 Effect of peat and artificially-coated sand rate on various physical analyses of the mix.

- Factor -				Pore Space			
Peat	Rate	Ksat	BD	Total	Macro	Micro	WHC
	%	cm hr^{-1}	g cc^{-1}	%			
With	0	187	1.52	40.2	28.3	11.9	7.8
	12.5	149	1.53	39.0	23.6	15.4	10.1
	25.0	84	1.46	44.4	29.0	15.3	10.6
	50.0	80	1.38	46.4	26.9	19.5	14.2
	75.0	79	1.32	47.7	20.0	27.7	21.0
Without	0	188	1.69	35.1	27.7	7.4	4.4
	12.5	185	1.63	36.5	27.4	9.1	5.6
	25.0	114	1.60	35.5	26.2	9.3	5.8
	50.0	79	1.52	41.4	27.9	13.4	8.8
	75.0	84	1.47	42.2	20.7	21.4	14.6
Factor		P value					
Peat		0.02	<0.01	<0.01	0.56	<0.01	<0.01
Rate		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Peat*Rate		0.15	0.46	0.07	0.13	0.09	<0.01

Field Study I 2001 - 2002

Based upon evaluation of glasshouse data, treatments were selected for use in the field. Because of physical limitations connected with having plots with lysimeters, a balanced factorial design was not an option. Treatments selected for use in the field were uncoated sand, uncoated sand with peat, naturally-coated sand with peat, and uncoated sand with peat plus artificially-coated sand. For purposes of convenience, uncoated sand amended with peat and artificially-coated sand will be referred to in this chapter as artificially-coated sand with peat, even though artificially-coated sand made up only 250 g kg^{-1} of the total mix.

Establishment

Selected physical properties of root-zone materials prior to establishment

Peat had a considerable influence on root-zone physical properties (Table 4-37). Uncoated sand without peat had high K_{sat}, exceeding the accelerated range of 30-60 cm hr^{-1} specified for putting green root zone mixes by the USGA (USGA Green Section Staff, 1993). The K_{sat} of uncoated, naturally-, and artificially-coated sand with peat were all lower, and within the USGA accelerated range. Peat decreased bulk density and increased water holding capacity. The presence of sand grain coatings increased water holding capacity. Artificially- and naturally-coated sand with peat had 17 % greater water holding capacity than uncoated sand with peat.

Peat had a greater impact on root zone physical properties in the mixes used in the field in comparison to the physical properties observed in glasshouse study Phase I (Table 4-1). In Phase I, no effect of peat on K_{sat} was observed on undisturbed, relatively

uncompacted samples. In this field study, however, USGA methods (Hummel, 1993) were used which dictate compaction of samples in order to better simulate field conditions. This compaction likely decreased macropore space of the treatments with peat, causing a decrease in K_{sat} of treatments with peat (Table 4-37).

Selected chemical properties of root-zone materials prior to establishment

Initial soil-test values showed little inherent nutrient content of uncoated sand and uncoated sand with peat (Table 4-38). Phosphorus and K did not differ greatly among the uncoated sand, uncoated sand with peat, an naturally-coated sand with peat. However, Ca and Mg were substantially greater for naturally-coated sand than for either uncoated sand or uncoated sand with peat. The soil-test values for P, K, Ca, and Mg in artificially-coated sand with peat were considerably greater than those of the other root-zone mixes, with the exception of Mg in the two coated sands. The acetic-acid extractable P (Pa) more or less represents "reserve P", as opposed to the water soluble P (Pw). Whereas Pa of the artificially-coated sand was 31 times that of the naturally-coated sand, Pw was only slightly more than three times greater suggesting that relative P leaching may not be as great for the artificially-coated sand, relative to the others, as might appear based on the difference in soil-test P.

Soil pH was substantially greater in the coated sands than in the uncoated sand, and was quite high for the artificially-coated sand (Table 4-38). As noted previously whereas the same clay was used for artificially-coated sand in all studies, the polymer resin used for the artificially-coated sand in Field Study I was different from the polymer

coating used in Phases I - III. For this reason, it is assumed that the pH of the artificially-coated sand used in Field Study I was related to the resin.

Peat and sand grain coating increased CEC (Table 4-38). Only mixes containing naturally- and artificially-coated had CEC values $\geq$ 6 cmol kg^{-1}, a benchmark value for optimal turfgrass/root-zone performance suggested by Petri and Petrovic (2001).

Oxalate extractable Fe and Al

Oxalate extractable Fe and Al of both uncoated and naturally-coated sand were very low (Table 4-39). Furthermore, oxalate extractable Fe and Al of naturally-coated sand used in Field Study was much less than that of the naturally-coated sand used in the Glasshouse Studies (Table 4-4). These data indicate a low potential for P sorption by the naturally-coated sand used in the Field Study. Artificially-coated sand generally had greater oxalate extractable Fe and Al than uncoated and naturally-coated sand because of the phyllosilicate clay.

'Tifdwarf' bermudagrass coverage rate during establishment

'Tifdwarf' establishment was affected by the presence of peat and secondly by artificially-coated sand (Table 4-40). Establishment rate was slowest in uncoated sand. Peat, probably because of increased moisture retention capability, greatly improved establishment in uncoated sand which is consistent with research by Nus et al., (1987), Bigelow et al., (2000), Waltz and McCarty, (2000), and Brown et al., (2000). There was, however, little difference in establishment rate between uncoated sand with peat and naturally-coated sand with peat. Whereas naturally-coated sand improved establishment rate in Phase I (Table 4-5), the naturally-coated sand used in Field Study I had less

influence on establishment rate (Table 4-40). The most rapid 'Tifdwarf' establishment rate was observed in artificially-coated sand. 'Tifdwarf' growing in artificially-coated sand had greater percent coverage on all observation dates, except 57 DAP, likely the result of increased water retention and nutrient content (Table 4-37, 4-38). These observations correspond to those made in the Artificially-coated Sand Rate Study (Fig. 4-3). Uncoated sand with peat, naturally-coated sand with peat, and artificially-coated sand with peat completed establishment between 60 and 75 DAP with uncoated sand without peat not reaching 100 % coverage until 90 DAP even though all treatments were fertilized with substantial amounts of N, P, K, Mg, and micronutrients.

Clipping production during establishment

Differences in clipping production (Table 4-41), measured as lawn mower clippings, somewhat reflected the differences observed in visual establishment rate (Table 4-40). The inclusion of peat in uncoated sand greatly improved clipping production from uncoated sand at 50, 57, 74, and 81 DAP. Interestingly, clipping production from naturally-coated sand was only greater than uncoated sand without peat 57 DAP. Clipping production from artificially-coated sand was greater than that of naturally-coated sand 57, 74, 81, and 88 DAP, and was greater than that of uncoated sand at all harvest periods except 88 DAP. However, it was never greater than uncoated sand with peat. The lack of significance between uncoated sand with peat and artificially coated sand with peat may have occurred in part because clippings were not collected until 38 DAP when coverage was becoming more similar. It was not possible to take clippings earlier, when greater coverage differences were observed between these two treatments.

Total clipping production over the establishment period was greatest in uncoated and artificially-coated sands with peat (Table 4-41). Late season grow-in conditions, such as shortening days and cloudy days, may have reduced the opportunity to observe differences among all treatments.

Potassium leaching during establishment

Potassium leaching was not influenced by peat during establishment (Table 4-42), but was much greater for the artificially-coated sand, which had higher initial quantity of K than the other mixes, during the first 51 DAP (Table 4-38). By 75 DAP, percolate K concentrations (Table A-9) from artificially-coated sand amended plots decreased to levels equal to unamended plots as soluble K was depleted from artificial-coating. The greater CEC of peat and naturally-coated sand did not reduce K leaching during establishment. Percolate K concentrations collected from uncoated sand with peat did not differ from uncoated sand alone suggesting either that sphagnum peat does little to reduce K leaching or that the K fertilization rate was too great for differences to exist (Table A-9). The latter explanation would be supported by the observation that in Phase I 2000, when K fertilization occurred monthly, the inclusion of peat at times helped to reduce K leached from uncoated sand (Table 4-7, 4-8).

Artificially-coated sand with peat had the greatest total K leached during Field Study I establishment (Table 4-44). In glasshouse study Phase I, the establishment phase, less total K leached from the artificially-coated sand treatments (Table 4-7). The artificially-coated sand used in the field study apparently served as a charged source of slow release K (Table 4-38). It is not possible to differentiate applied K in percolate

water from that initially contained in the artificially-coated sand. Despite diversities in CEC, there were no differences in total K leached between uncoated sand, uncoated sand with peat, and naturally-coated sand with peat. Approximately, 71.2, 31.2, and 49.2 % of applied K leached from uncoated sand, uncoated sand with peat, and naturally-coated sand with peat, respectively. In comparison, during the Phase I 2000 establishment study when a total of 25 g K was applied in three fertilizations, 31% of applied K leached from uncoated sand and 16% from naturally-coated sand. It appears that the naturally-coated sand used in Field study I was less capable of K retention than the naturally-coated sand used in the glasshouse study. This likely is because the sand used in the field study was commercially washed and graded, which probably displaced coatings from the sand surfaces, whereas the sand used in the glasshouse study was not subjected to such processing. In addition, it is possible that colloids observed in the percolate water leached from naturally-coated sand treatments may have been responsible for colloid-facilitated transport of K (Ryan and Gschwend, 1994). In a similar study, Chung et al. (1999) reported that 11% of total K, applied to sodded bermudagrass turf in total at 15 g K m^{-2} as KCl, was leached from a USGA root-zone mix containing uncoated sand.

Phosphorus leaching during establishment

Phosphorus leaching was influenced little by coating and peat (Table 4-43).. In addition, phosphorus leaching generally increased with time. The presence of natural sand grain coatings did not reduce P leaching in the field, whereas they did in previous glasshouse studies (Tables 4-10, 4-18, 4-29) (Brown et al. 2000). Furthermore, greater P leaching was observed from naturally-coated sand with peat than uncoated and uncoated

sand with peat 2, 5, 20, 28, and 39 DAP. Despite greater inherent P content, the artificially-coated sand with peat treatment percolate P concentrations did not differ from those of uncoated sand, uncoated sand with peat, and naturally-coated sand with peat after the first 10 DAP (Appendix). From 42 to 90 DAP no differences in P leached were observed among the treatments. By 28 DAP, the leachate P concentration of all treatments was > 0.3 mg L^{-1}, the concentration that has been reported to cause surface water eutrophication (Petrovic, 1995) (Appendix). Wong et al. (1998) also observed leachate P concentration from greens > 0.3 mg L^{-1} , ranging from 3.25 to 10.00 mg L^{-1}, and further stated that added P must have exceeded both plant requirements and absorption capacity of the sandy root zone. It is likely that this also occurred in this field study because of the high rate and frequency of P fertilization.

Unlike as in the previous studies Phases I - III and Brown et al. (2000), naturally-coated sand did not reduce total P leached (Table 4-38). Brown et al. (2000) only observed a loss of 7% of applied P from naturally-coated sand with peat as compared to a loss of 33 % of applied P in this field study during establishment. In Phase I 2000 establishment, naturally-coated sand with or without peat had reduced applied P loss to less than 1 %. Clearly properties of the naturally-coated sand used in this field study, such as very low oxalate extractable Fe and Al (Table), did not favor P retention.

Uncoated sand and uncoated sand with peat performed more similarly to results observed in Phase I 2000 and previous studies (Table 4-44). Uncoated sand and uncoated sand with peat lost 32 and 11 % of applied P, respectively. Brown et al. (2000) observed a loss of 11 % and 14 % applied P from uncoated sand without peat and uncoated sand

with peat. Wong et al. (1998) observed that 38 % of P applied to a sandy putting green root zone was lost in leachate.

Surprisingly, total P leached was not greater from artificially-coated sand than uncoated sand, uncoated sand with peat, and naturally-coated sand with peat (Table 4-44) despite far greater initial soil-test P (Table 4-38).

Relative K and P leached during establishment

Because the influence of inherent K and P levels was observed during establishment (Table 4-44), relating K and P leached to inherent K and P root zone levels (Table 4-45) may provide more information regarding K and P leaching from treatments. Relative K and P leached accounts for K and P applied as fertilizer and K and P inherent to treatments. Relative K and P leached is calculated by dividing total K and P leached by the sum of applied K and P and 30 cm root zone K and P levels.

Relative K leaching was generally affected by the addition of peat and artificially-coated sand (Table 4-45). While there were no differences in total K leached among uncoated sand, uncoated with peat, and naturally-coated sand with peat during establishment (Table 4-44), the inclusion of peat generally decreased relative K leached from uncoated and naturally-coated sand in comparison to uncoated sand alone. Increased K retention of uncoated and naturally-coated sand amended with peat versus uncoated sand alone is best observed when the K contributed by the peat is accounted for. Artificially-coated sand with peat generally had the highest relative K leached even when normalizing for the K content of artificially-coated sand (Table 4-45). The CEC of

artificially-coated sand with peat (Table 4-38) was unable to reduce relative K leached in comparison to the other treatments because of such high inherent K content (Table 4-38).

Because P is less mobile, increasing the P content of root zone with peat and artificially-coated sand amendments generally did not increase relative P leached during establishment (Table 4-39). Naturally-coated sand with peat, having double the P content of uncoated sand with peat (Table 4-38), generally had a higher relative P leached than uncoated sand with peat. Relatively less P leached from uncoated sand with peat than uncoated sand alone. In addition, relatively less P leached from artificially-coated sand with peat than the other treatments despite a high P content (Table 4-38).

K uptake during establishment

The presence of peat generally had the greatest effect on K uptake during establishment (Table 4-46). Uncoated sand with peat had greater K uptake on all harvest dates than uncoated sand alone. Although the inclusion of peat in uncoated sand helped to increase K uptake relative to uncoated sand alone, in part because of greater clipping production, the inclusion of peat also increased K tissue concentration of the uncoated sand treatment 38, 57, and 81 DAP (Table A-13). In Phase I 2000 establishment, peat also improved K uptake because of increased clipping production and at times because of increased tissue K concentration (Table 4-9, A-1). Artificially-coated sand with peat also increased K uptake at all harvest dates relative to uncoated sand. Artificially-coated sand with peat increased tissue K concentration relative to uncoated sand at 38, 50, 57, and 81 DAP (Table A-13). Naturally-coated sand with peat, however, only increased K uptake relative to uncoated sand at 38 and 57 DAP with an increase in tissue K concentration

occurring only at 57 DAP. In Phase I 2000, naturally-coated sand had increased K uptake over that of uncoated sand throughout the establishment period (Table 4-9, A-1).

Generally, there was no difference in K uptake between artificially-coated sand with peat and uncoated sand with peat (Table 4-46). Perhaps because of the high K fertilization rate and frequency (2.7 g K m^{-2} or slightly more than 0.5 lb K 1000 ft^2 $week^{-1}$), artificially-coated sand did not increase K uptake relative to that of uncoated sand with peat during establishment, where as a difference was previously observed in Phase I 2000 (Table 4-9).

Naturally-coated sand with peat did not increase K uptake over that of uncoated sand with peat at any of the harvest dates during establishment (Table 4-46). In fact, K uptake from naturally-coated sand with peat actually was less than that of uncoated sand with peat at every harvest date. Naturally-coated sand with peat did not affect K uptake, perhaps for the same reasons discussed relative to K leaching.

The inclusion of peat, and to some degree the presence of coatings, increased total K uptake during establishment (Table 4-46). Uncoated sand had the lowest total K uptake, accumulating only 2% of the K applied during establishment. Total K uptake was greater from naturally-coated sand with peat than uncoated sand but was less than that of uncoated and artificially-coated sand with peat. There was no difference in total K uptake between uncoated sand with peat and artificially-coated sand with peat, with both treatments having accumulated 4% of the applied K. In Phase I 2000 naturally- and artificially-coated sand had increased total K uptake relative to uncoated sand (Table 4-9).

P uptake during establishment

The inclusion of peat in uncoated sand increased P uptake (Table 4-47). Uncoated sand with peat increased P uptake at all harvest dates relative to uncoated sand. The increase in P uptake is likely attributable to an increase in clipping production, since tissue P concentration of uncoated sand with peat was only greater than that of uncoated sand once during establishment (57 DAP). Similar results were observed in Phase I 2000 where peat improved P uptake during establishment primarily because of increased clipping production rather than an increase in tissue P concentration (Table 4-10, A-2).

The influence of sand grain coatings on P uptake varied during establishment (Table 4-47). There was greater P uptake in artificially-coated sand with peat than uncoated sand and naturally-coated sand with peat at all harvest dates. There was, however, no difference between artificially-coated sand with peat and uncoated sand with peat during establishment. Furthermore, at all harvest dates greater P uptake was observed from uncoated sand with peat than naturally-coated sand with peat. Most notably, naturally-coated sand did not increase P uptake over that of uncoated sand. In Phase I 2000, the presence of natural sand grain coatings only increased P uptake at two of four harvest dates (29 and 58 DAP) during establishment with those increases occurring only because of greater clipping production and not increased tissue P concentration (Table 4-10, A-2).

The inclusion of peat increased total P uptake during establishment while the presence of sand grain coatings was less clear (Table 4-47). Uncoated sand had the smallest quantity of total P uptake during establishment. In phase I 2000 the inclusion of

peat had also increased total P uptake (Table 4-10). There was no difference between uncoated sand with peat and artificially-coated sand with peat. In phase I 2000 the presence of artificially-coated sand had increased total P uptake (Table 4-10). Naturally-coated sand with peat did increase total P uptake relative to uncoated sand, however, that increase is likely related to the inclusion of peat. In phase I 2000 naturally-coated sand had also increased total P uptake over that of uncoated sand (Table 4-10). However, that increase in total P uptake can also be attributed to increased clipping production observed because of the presence of peat in the root zone mixture (Table 4-6).

Relative K and P uptake during establishment

The inclusion of peat generally increased relative K uptake in comparison to uncoated sand alone (Table 4-48). Relative K uptake of uncoated and naturally-coated sand amended with peat was increased over that of uncoated sand probably because of increased clipping production. The lowest relative K uptake was generally observed from artificially-coated sand with peat.

As was observed with K, the addition of peat to uncoated and naturally-coated sand generally increased relative P uptake in comparison to uncoated sand alone (Table 4-48). In general, the lowest relative P uptake was observed from artificially-coated sand with peat.

Volumetric moisture content during establishment

Differences in moisture content among treatments were observed throughout the grow-in period using a ThetaProbe which determines moisture content to a depth of 6 cm (Table 4-49). Previous research has shown that ThetaProbe readings show a strong linear

response to soil moisture content (Hanson and Peters, 2000). Uncoated sand without peat had the lowest moisture content regardless of irrigation frequency. The addition of peat to uncoated sand improved moisture content 3 - 4 % during establishment. Perhaps because of their clay coatings, naturally-coated sand with peat and artificially-coated sand with peat had the greatest root zone moisture content during grow-in. Even though plots were irrigated regularly, lower soil moisture, especially in the uncoated sand without peat, may have contributed to slower establishment (Table 4-40) and less clipping production (Table 4-41). Although volumetric moisture content of treatments measured in the field were less than those of volumetric moisture content measured using physical analysis techniques (Table 4-37), the exact same trends in volumetric moisture content were observed in the field. None of the treatments, however, had volumetric moisture contents $\geq$ 15% during establishment, a suggested level of volumetric moisture for a successful sand-based root zone (Bingaman and Kohnke, 1970).

Selected chemical properties of root zone mixes at the conclusion of establishment

Soil pH of treatments differed at the end of the grow-in period. Uncoated sand had the highest pH (Table 4-50), whereas it had been among the lowest at the start of the study (Table 4-38). High pH irrigation water and low buffer capacity of uncoated sand likely contributed to the substantial increase in pH. Elevated soil pH in unbuffered sand soils at the FLREC previously has been attributed to calcium bicarbonate in the irrigation water at that location (Snyder et al., 1979). Uncoated sand with peat had the lowest pH value, but it too increased considerably during the study (from 4.3 to 6.8). The addition of sphagnum peat, an acidic peat source, with high CEC and buffering capacity,

contributed to the lower pH observed for uncoated sand with peat relative to the same sand without peat. In contrast to the uncoated sand, the pH of artificially-coated sand decreased very substantially during the grow-in study. The acidifying effect of weekly fertilization may have contributed to the reduction in pH. The pH of naturally-coated sand with peat decreased only slightly if at all during establishment.

Acetic-acid extractable P (Pa) of all treatments was greater at the completion of the grow-in period (Table 4-50) relative to the beginning of the study (Table 4-38) as a result of the frequent P fertilization conducted during grow-in. In addition, water soluble P (Pw) of the root zone mixes increased with the exception of artificially-coated sand with peat which essentially remained constant. Artificially-coated sand with peat had the greatest acetic-acid extractable and water soluble P at the end of establishment. But whereas Pw appeared to decrease slightly relative to the initial soil-test, Pa continued to increase, indicating additional ability of this material to absorb and retain P. There was no difference in Pa and Pw among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat.

Differences in soil K were observed following the grow-in period. Artificially-coated sand with peat continued to have the greatest quantity of soil test K (Table 4-50), although it was down considerably from the pre-establishment value (Table 4-38). High soil K in the artificially-coated sand with peat treatment can be attributed to inherent K levels of the artificially-coated sand. Uncoated sand with peat had greater soil K than uncoated sand. Interestingly, despite the presence of peat and greater CEC, there was no difference between naturally-coated sand with peat and uncoated sand.

Differences in soil Ca and Mg were observed among root zone mixes at the end of the grow-in period (Table 4-50). Artificially-coated sand had the highest quantity of Ca and Mg, followed by naturally-coated sand with peat, uncoated sand with peat, and uncoated sand. Soil Ca levels of uncoated sand with peat and uncoated sand were elevated with respect to initial quantities, probably as a result of Ca inputs from irrigation.

Differences in soil Mg at the end of grow-in can likely be attributed to inherent levels of Mg in the root zone mixes, with a lesser contribution from fertilizer. Artificially-coated sand with peat and naturally-coated sand with peat had higher levels of Mg in pre-construction materials and continued to have higher Mg at the end of grow-in. There was no difference between uncoated sand and uncoated sand with peat at the conclusion of the grow-in period. Furthermore, only uncoated sand experienced an increase, which was small, in soil Mg relative to pre-construction Mg levels.

Table 4-37 Saturated hydraulic conductivity (K_{sat}), volumetric water holding capacity (θv), and bulk density (φ_{BD}) of the four root-zone media prior to construction field study I.

Root-zone	K_{sat}	θ_V	φ_{BD}
	- -cm h^{-1}- -	L L^{-1}	g cm^{-3}
Uncoated	86.0a†	0.10c	1.70a
Uncoated with peat	49.4b	0.18b	1.62b
Naturally with peat	48.4b	0.22a	1.58b
Artificially with peat	36.1b	0.21a	1.57b

†Any means followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-38 Selected chemical properties of root zone media used in field study I prior to construction.

Root zone	pH	CEC	Pa	Pw	K	Ca	Mg
		$cmol_c$ kg^{-1}	- - - - - - - - -	- - - - mg L^{-1}	- - - -	- - - - -	- - -
Uncoated Sand	5.5	0.0	1	1	1	0	0
Uncoated Sand and Peat	4.3	2.1	5	3	7	29	11
Naturally-Coated Sand	5.4	4.3	4	0	1	92	2
Naturally-Coated Sand and Peat	7.3	6.4	10	6	3	243	105
Artificially-Coated Sand	7.4	10.1	1119	8	2142	1369	496
Artificially-Coated Sand and Peat	10.0	6.0	316	19	508	481	126
Emathlite Clay		7.0	71.4	762	5	52	978 358

Pw - water-extractable P

Pa, K, Ca, Mg - acetic acid extractable nutrients

Table 4-39 Oxalate extractable P, Al, and Fe of materials used field studies.

Type		P	Al	Fe
Coating	Peat	- - - - - - - - - - - - - -	mg kg^{-1} - - - - - - - - - - - - - -	
Uncoated	without	7.6(±0.3)	bdl	bdl
Uncoated	with	8.7(±7.2)	2.1(±0.4)	bdl
Naturally	without	bdl	bdl	bdl
Naturally	with	18.9(±0.4)	57.3(±0.4)	bdl
Artificially	without	1022.5(±31.2)	166.4(±1.1)	22.7(±0.9)
Artificially	with	217.2(±11.9)	87.3(±2.7)	9.5(±1.5)
Emathlite Clay		12230(± 430)	3006(± 126)	1561(± 179)

Table 4-40 Influence of root zone media on 'Tifdwarf' coverage as a function of time after planting field study I 2001 - 2002.

Root zone	Days after planting					
	14	21	35	38	50	57
	Coverage (%)					
Uncoated	5.8c†	15.0d	46.2c	36.2c	45.0c	56.2c
Unc. + Peat	9.5b	25.0c	60.0b	56.2b	77.5b	87.5ab
Nat. + Peat	7.0bc	28.8b	55.0bc	52.5b	72.5b	83.8b
Art. + Peat	16.2a	41.2a	76.2a	71.2a	87.5a	92.5a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-41 Influence of root zone media on clipping production as a function of time after planting field study I.

Root zone	Days after planting						
	38	50	57	74	81	88	Total
	$g\ m^{-2}$						
Uncoated	10.6b†	3.3c	1.4c	11.7b	26.6b	13.6ab	70.4b
Unc. + Peat	21.6ab	10.7a	4.2a	20.8a	44.0a	14.8a	116.1a
Nat. + Peat	17.6ab	5.2bc	2.8b	14.3b	26.6b	8.2c	74.6b
Art. + Peat	28.7a	7.0b	5.0a	23.6a	41.3a	12.5b	118.2a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-42 Influence of root zone media on potassium leaching as a function of time after planting establishment field study I 2001 -2002.

Root zone	Days after planting																
	2	5	10	15	20	23	28	32	39	42	45	51	63	71	75	81	90
	$g\ m^{-2}$																
Uncoated	1.33b†	0.32b	0.39b	0.39b	0.62b	0.02b	1.59b	2.08b	0.82b	0.90ab	0.45b	3.78ab	3.25a	1.33a	0.49a	0.97a	1.08a
Unc. + Peat	0.69b	0.15b	0.08b	0.29b	0.37b	0.02b	2.38b	1.23b	0.90b	0.54b	0.40b	0.35b	1.35a	0.18a	0.33a	0.38a	0.43a
Nat. + Peat	0.41b	1.09b	0.17b	0.17b	0.38b	0.08b	2.02b	1.40b	1.03b	0.78ab	0.82b	2.59ab	1.64a	0.75a	0.65a	0.92a	1.02a
Art. + Peat	27.48a	18.21a	7.99a	15.19a	8.96a	0.81a	20.23a	8.58a	6.47a	2.45a	2.64a	7.22a	3.25a	1.06a	1.23a	0.90a	1.49a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-43 Influence of root zone media on phosphorus leaching as a function of time after planting establishment field study I 2001 -2002.

Root zone	Days after planting																
	2	5	10	15	20	23	28	32	39	42	45	51	63	71	75	81	90
	$g\ m^{-2}$																
Uncoated	0.01b†	0.01c	0.02a	0.09a	0.04b	0.00a	0.31b	1.35a	0.29b	0.46a	0.05a	0.40a	0.44a	0.50a	0.22a	0.50a	0.42a
Unc. + Peat	0.03b	0.25b	0.03a	0.02a	0.02b	0.00a	0.25b	0.25b	0.35b	0.34a	0.08a	0.04a	0.07a	0.03a	0.07a	0.07a	0.16a
Nat. + Peat	0.33a	0.45a	0.23a	0.14a	0.18a	0.02a	0.76a	0.41b	0.88a	0.48a	0.22a	0.25a	0.40a	0.26a	0.20a	0.38a	0.57a
Art. + Peat	0.34a	0.46a	0.13a	0.08a	0.06ab	0.01a	0.18b	0.14b	0.33b	0.19a	0.09a	0.16a	0.13a	0.09a	0.12a	0.12a	0.25a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-44 Influence of root zone media on total phosphorus and potassium leached during field study I establishment.

Root zone	Phosphorus	P % of applied	Potassium	K % of applied
	- - g m^{-2} - -		- - g m^{-2} - -	
Uncoated	5.83a†	31.5	23.05b	71.2
Unc. + Peat	2.06a	11.1	10.09b	31.2
Nat. + Peat	6.17a	33.3	15.94b	49.2
Art. + Peat	2.88a	15.6	133.02a	410.9

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-45 Potassium and P leached during Field Study I establishment relative to total K and P added and soil-test† K and P prior to Field Study I establishment.

	K	P
	- - - - - - - % - - - - - - - -	
Uncoated sand	65	31
Uncoated sand with peat	29	10
Naturally-coated sand with peat	48	29
Artificially-coated sand with peat	85	3

† Soil-test K and P are based on 30 cm root zone.

Table 4-46 Influence of root zone media on bermudagrass K uptake as a function of time after planting field study I.

Root zone	Days after planting						
	38	50	57	74	81	88	Total
	- - - - - - - - - - - - - - K mg m^{-2} - - - - - - - - - - - - -						- K g m^{-2} -
Uncoated	46.6c†	23.5c	14.4c	370.9b	161.1c	185.4c	0.6c
Unc. + Peat	263.6a	117.5a	55.3a	629.2a	214.9a	359.4a	1.4a
Nat. + Peat	143.1b	41.9c	36.8b	445.3b	116.4c	213.8bc	0.9b
Art. + Peat	325.1a	79.7b	63.4a	661.6a	197.9ab	309.0ab	1.4a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-47 Influence of root zone media on bermudagrass P uptake as a function of time after planting field study I.

Root zone	Days after planting						
	38	50	57	74	81	88	Total
	- - - - - - - - - - - - - - P mg m^{-2} - - - - - - - - - - - - -						- P g m^{-2} -
Uncoated	17.8c†	9.7c	4.6c	127.8b	53.8b	58.3b	0.2c
Unc. + Peat	66.3a	38.9a	16.7a	199.8a	68.9a	104.0a	0.4a
Nat. + Peat	40.3b	14.2c	11.0b	143.4b	39.0c	64.1b	0.3b
Art. + Peat	81.1a	25.8b	19.8a	208.8a	61.0ab	93.2a	0.4a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-48 Potassium and P uptake during Field Study I establishment relative to total K and P added and soil-test† K and P prior to Field Study I establishment.

	K	P
	-------%--------	
Uncoated sand	1.7	1.1
Uncoated sand with peat	4.0	2.0
Naturally-coated sand with peat	3.0	1.4
Artificially-coated sand with peat	0.9	0.4

† Soil-test K and P are based on 30 cm root zone.

Table 4-49 Influence of root zone media on soil moisture content as a function of time after planting field study I.

Root zone	Days after planting†					
	7	10	14	16	23	35
	- - - - - - - - Volumetric moisture content - - - - - - - -					
Uncoated	0.06c‡	0.06c	0.07c	0.02c	0.04c	0.04c
Unc. + Peat	0.10b	0.11b	0.10b	0.06b	0.08b	0.08b
Nat. + Peat	0.13a	0.13a	0.12a	0.08a	0.10a	0.10a
Art. + Peat	0.13a	0.13a	0.13a	0.08a	0.10a	0.10a

†Irrigation was applied four times per day the first fourteen days after planting then reduced to once daily thereafter.

‡Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-50 Selected properties of root zone media upon completion of establishment field study I.

Type	pH	Pa	Pw	K	Ca	Mg
		- - - - - - - - - - mg L^{-1} - - - - - - - - - -				
Uncoated Sand	8.0a †	20.5b	7.0b	5.2c	50.3d	3.7c
Uncoated Sand and Peat	6.8d	22.2b	8.0b	9.2b	134.1c	9.0c
Naturally-Coated Sand and Peat	7.1c	23.7b	6.7b	8.1bc	231.6b	35.4b
Artificially-Coated Sand and Peat	7.5b	368.9a	15.4a	83.2a	462.5a	67.0a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Pw - water-extractable P

Pa, K, Ca, Mg - acetic acid extractable nutrients

Clipping production during maintenance

Differences in clipping production were observed throughout the maintenance period when P and K fertilization had ceased (Table 4-51). Generally, there were no differences between artificially-coated sand with peat and uncoated sand with peat early in the maintenance period, 143, 157, and 187 DAP, when soil P and K were likely still adequate as a result of fertilization during establishment (Table 4-50). However, as soil P and K depleted during maintenance, the presence of artificially-coated sand increased clipping production 200 and 214 DAP relative to the other treatments. In Phase II 2001 the presence of artificially-coated sand increased clipping production over that of uncoated sand throughout the maintenance period (Table 4-14). With regards to naturally-coated sand with peat, only at 130 DAP was clipping production in this mix greater than in uncoated sand. At no point was clipping production in naturally-coated sand with peat greater than in uncoated sand with peat or artificially-coated sand with peat. In Phase II 2001 naturally-coated sand had increased clipping production relative to uncoated sand, an observation not made during this field study maintenance period (Table 4-14). From 187 to 214 DAP no difference was observed among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat.

Artificially-coated sand with peat had the greatest total clipping accumulation during the maintenance period (Table 4-51). In Phase II 2001 the presence of artificially-coated sand increased total clipping production over that of uncoated and naturally-coated sand (Table 4-14). The presence of peat increased total clipping production of uncoated sand. However, the inclusion of peat in naturally-coated sand did not increase total

clipping production relative to uncoated sand. In addition, there was no difference in total clipping production between naturally-coated sand with peat and uncoated sand with peat. In Phase II 2001 the inclusion of peat had increased total clipping production of all sand types, but in this field study it failed to increase total clipping production of naturally-coated sand.

Potassium leaching during maintenance

Although K fertilization ceased at the start of the maintenance period, the effects of weekly K fertilization over the 12 week establishment period were evident from 99 to 125 DAP in that no difference in K leaching was observed among treatments during this time because all treatments were so flooded with K that there was an excess in all plots (Table 4-52). Greater K leaching was observed from artificially-coated sand with peat than other treatments 130 to 199 DAP, probably both due to greater inherent K content and to more K retained during the establishment period (Table 4-52). Throughout Phases I - III the presence of artificially-coated sand had decreased K leached. In the field study, however, because of the change in coating composition noted above, this observation was not made during the maintenance period. Heavy rain events occurred two days prior to the 140 DAP sampling date with approximately 20 cm of rainfall recorded. More K leached from naturally-coated sand with peat than uncoated sand and uncoated sand with peat at 140 DAP following those heavy rainfall events. In phase II 2001 naturally-coated sand, like artificially-coated sand, had decreased K leaching relative to uncoated sand (Table 4-15). During the maintenance period there was no difference in K leached between uncoated sand with peat and uncoated sand during the maintenance period.

With respect to total K leaching, more K leached from artificially-coated sand with peat than from the other treatments (Table 4-52). Greater total K leached from artificially-coated sand with peat can be attributed to the K content of the artificial coating (Table 4-38). In Phase I - III artificially-coated sand had decreased total K leached because of the CEC associated with the coating (Tables 4-7, 4-8, 4-15, 4-25).

There was no difference in total K leached between uncoated sand, uncoated sand with peat, and naturally-coated sand with peat (Table 4-52).

Phosphorus leaching during maintenance

As was the case with K, P fertilization was discontinued at the start of the maintenance period. No difference in P leached was observed between treatments from 99 to 130 DAP. Two days prior to the 140 DAP sampling date approximately 20 cm of rainfall were recorded. Interestingly, at 140 DAP less P leached from uncoated sand than uncoated sand with peat and naturally-coated sand with peat (Table 4-53), perhaps because P mineralized from peat and P retained during establishment was lost as a result of the heavy rainfall event. During establishment, uncoated sand had lost approximately 31 % of the applied P, which reduced the quantity available for loss during the maintenance period since no other source of P was available. Despite greater soil-test P than uncoated sand with peat (Table 4-50), there was no difference in P leached from artificially-coated sand with peat than uncoated sand with peat even following heavy rainfall events recorded 138 and 139 DAP. Furthermore, percolate P concentration from artificially-coated sand with peat was $\leq$ to that of naturally-coated sand with peat and uncoated sand with peat (Table A-16). More P leached, however, from naturally-coated

sand with peat than artificially-coated sand with peat following the heavy rainfall events prior to the 140 DAP sampling. During Phases I - III naturally-coated sand had substantially decreased P leaching relative to artificially-coated sand (Tables 4-10, 4-18, 4-29).

Percolate P concentration during maintenance should be of concern. Even without additional P fertilization leachate P concentrations of all treatments exceeded 0.3 mg L^{-1} during maintenance (Petrovic, 1995)(Table A-16). Although P is generally considered less mobile than other nutrients, such as N and K, several authors have noted excessive P leaching from established putting green root zones (Wong et al., 1998; Shuman, 2001).

There was no difference in total P leached among the treatments (Table 4-53).

Relative K and P leached during maintenance

As observed with total K leached (Table 4-52), there was no difference in relative K leached among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat during maintenance (Table 4-54). There was more total K leached from artificially-coated sand than the other treatments probably because of inherent K content. However, when normalizing for K content, there was no difference in relative K leached among artificially-coated sand with peat and the other treatments.

While there was no difference in total P leached among the treatments during maintenance (Table 4-53), differences in relative P leached were observed (Table 4-54). Naturally-coated sand with peat had greater relative P leached than uncoated sand and artificially-coated sand with peat. There was no difference in relative P leached between

uncoated sand with peat and naturally-coated sand with peat.

K uptake during maintenance

In general, the inclusion of peat and artificially-coated sand increased K uptake during the maintenance period (Table 4-55). The presence of peat in uncoated sand increased K uptake relative to uncoated sand throughout maintenance with one exception at 200 DAP. The increase in K uptake of bermudagrass associated with the inclusion of peat in uncoated sand is best explained by the increase in clipping production associated with peat (Table 4-51) since there was no increase in tissue K concentration in the presence of peat (Table A-17). During Phase III the presence of peat increased K uptake (Table 4-27) without increasing tissue K concentration (Table A-5). The inclusion of peat in naturally-coated sand, however, did not increase K uptake during maintenance relative to uncoated sand.

The addition of artificially-coated sand to uncoated sand with peat increased K uptake from the uncoated sand with peat root zone during maintenance (Table 4-55). Although, in several cases, there was no statistical difference in clipping production (Table 4-51) and tissue K concentration (Table A-17) between uncoated sand with peat and artificially-coated sand with peat, a general increase both in clipping production (Table 4-51) and tissue K concentration (Table A-17) was observed between the two treatments during maintenance.

The presence of natural sand grain coatings did not increase K uptake relative to uncoated sand during maintenance (Table 4-55). From 130 to 187 DAP greater K uptake was observed from uncoated sand with peat than naturally-coated sand with peat. As soil

K levels depleted, from 200 to 214 DAP, a difference in K uptake between uncoated sand with peat and naturally-coated sand with peat did not exist. In Phase II 2001 the presence of naturally-coated sand increased K uptake (Table 4-17) and tissue K concentration (Table A-3) relative to uncoated sand with or without peat.

The inclusion of artificially-coated sand and peat increased total K uptake during maintenance (Table 4-55). The presence of peat in uncoated sand increased total K uptake 44 % relative to uncoated sand. In addition, artificially-coated sand grains increased total K uptake 89 % relative to uncoated sand, and increased total K uptake 31 % over that of uncoated sand with peat. There was no difference in total K uptake between uncoated and naturally-coated sand with peat.

Phosphorus uptake during maintenance

The inclusion of artificially-coated sand and at times peat increased P uptake during establishment (Table 4-56). The addition of peat to naturally-coated sand only increased P uptake 214 DAP when soil P would be lowest (Table 4-56) because P fertilization was suspended following establishment. The presence of peat in uncoated sand, however, did increase P uptake from uncoated sand at every sampling date except 200 DAP. The inclusion of artificially-coated sand increased P uptake relative to uncoated sand throughout the maintenance period. The increase in P uptake associated with artificially-coated sand and peat is best explained by increased clipping production (Table 4-51) and tissue P concentration (Table A-18). In Phase II 2001 the presence of artificially-coated sand also increased P uptake (Table 4-20) and tissue P concentration relative to uncoated sand (Table A-4).

The addition of artificially-coated sand to uncoated sand with peat also increased P uptake relative to uncoated sand with peat 157, 200, and 214 DAP when soil-test P might have been depleting because of uptake and leaching. This increase in P uptake is due primarily to increased clipping production and in part increased tissue P concentration (Table A-18). Finally, artificially-coated sand increased P uptake relative to naturally-coated sand with peat throughout maintenance. In Phase II 2000 artificially-coated sand increased P uptake (Table 4-20) and tissue P concentration (Table A-4) relative to naturally-coated sand.

The inclusion of peat and artificially-coated sand increased total P uptake during maintenance (Table 4-56). Both uncoated sand with peat and naturally-coated sand with peat increased total P uptake by 50 % relative to uncoated sand. Artificially-coated sand with peat increased total P uptake 100% and 33% relative to uncoated sand alone and naturally-coated sand with peat. In both Phase II (2001) and III (2002) artificially-coated sand increased total P uptake relative to uncoated and naturally-coated sand (Table 4-20, 4-29).

<u>Soil moisture content during maintenance</u>

Differences in moisture content were detected throughout the maintenance period (Table 4-57). Only artificially-coated sand with peat had a moisture content frequently $\geq$ 0.15. Bingham and Kohnke (1970) suggest, as a benchmark, that most successful sand-based root zones contain $\geq$ 0.15 water by volume. At 140 DAP there was no difference in soil moisture between naturally-coated sand and artificially-coated sand perhaps because approximately eight cm of rainfall had been recorded 138 and 139 DAP. Naturally-

coated sand with peat had greater soil moisture content than uncoated sand with peat 127, 140, 154, and 182 DAP. Uncoated sand had the lowest soil moisture at all sampling times during maintenance. Even after more than 20.5 cm of rainfall had been recorded from 138 - 139 DAP volumetric moisture content of uncoated sand remained the lowest with only seven percent (0.07) measured 140 DAP (Table 4-57).

Selected chemical properties of root zone materials at the conclusion of the maintenance.

The pH of values of all treatments at the end of the maintenance period decreased relative to pH values measured upon completion of the grow-in period (Table 4-58). The decrease in pH can be attributed to the acidifying nitrogen source (ammonium sulfate) used during maintenance fertilization. Uncoated sand had the highest pH at the end of maintenance, just as it was highest at the conclusion of the establishment period. In the uncoated sand treatment, which had a very high pH (8.0) at the start of the maintenance phase, the acidifying effect of N fertilization was partially balanced by irrigation with a basic water source common to south Florida (Snyder et al., 1979). The pH of artificially-coated sand with peat was slightly greater than both uncoated sand and peat and naturally-coated sand with peat, but was substantially lower than the excessively high starting value (Table 4-38). There was no difference in pH between uncoated sand with peat and naturally-coated sand with peat.

There were differences in CEC among all four root zone media at the conclusion of the maintenance period (Table 4-58). Artificially-coated sand with peat continued to exhibit the highest CEC of all treatments with a value $\geq$ 6 cmol kg^{-1}, which is a CEC value suggested as a benchmark for sand based root zone mixes (Petri and Petrovic,

2001). Furthermore, the CEC of artificially-coated sand with peat appears to have remained constant throughout the field study. The CEC of uncoated sand with peat was greater than that of uncoated sand alone, and of naturally-coated sand with peat. In addition, the CEC of uncoated sand with peat increased during the field study, perhaps due to an increase in organic matter content. Surprisingly, the CEC of naturally-coated sand decreased relative to pre-construction values. This decrease in the CEC of naturally-coated sand may have resulted from elluviation of poorly cemented sand grain coatings which were observed in percolate water during sampling throughout establishment and maintenance. Furthermore, the physical stresses imposed on naturally-coated sand during the mining and sizing process may have contributed to loosening of sand grain coatings. The CEC of uncoated sand remained at zero during the field study.

Both Pa and Pw soil P decreased for all treatments (except for Pw in artificially-coated sand) during the maintenance period when no P fertilizer was applied (Table 4-58). Guertal (2001) also observed a rapid decline in extractable soil-test P in a USGA-type putting green three months following P fertilization with additional P fertilization necessary in order to meet soil-test recommendations. Artificially-coated sand Pa and Pw generally changed only slightly during the maintenance period relative to post-establishment levels (Table 4-50). Although there was no difference in P leached between artificially-coated sand and the other treatments during maintenance (Table 4-53), Pa and Pw of artificially-coated sand was much greater than that of uncoated sand, uncoated sand with peat, and naturally-coated sand with peat. There was no difference in Pa among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat.

However, less Pw was measured in uncoated sand than uncoated sand with peat and naturally-coated sand with peat at the end of the maintenance period.

Despite the lack of K fertilization throughout the maintenance period, soil-test K remained similar to that measured at the conclusion of the establishment period, with the exception of artificially-coated sand with peat. Although artificially-coated sand with peat continued to leach K, as was shown in the leachate data (Table 4-52), artificially-coated sand still had the highest soil-test K at the conclusion of the maintenance period. There were no differences in soil-test K among uncoated sand, uncoated sand with peat, and naturally-coated sand.

Unlike K, soil test Ca levels of all treatments, except artificially-coated sand with peat, increased during the maintenance period, probably as a result of Ca in the irrigation water. Soil test Ca of artificially-coated sand, however, remained the greatest of all treatments despite having a lower soil test Ca value relative to establishment. There was no difference in soil Ca among, uncoated sand, uncoated sand with peat, and naturally-coated sand.

Soil test Mg of all treatments decreased relative to pre-maintenance levels. Artificially-coated sand with peat and naturally-coated sand with peat had greater soil test Mg than uncoated sand and uncoated sand with peat. There was no difference in soil test Mg between uncoated sand and uncoated sand with peat.

Selected physical properties of root zone materials at the conclusion of the maintenance.

The inclusion of peat had the greatest impact on physical properties of the root zone mixes (Table 4-59). Uncoated sand without peat had the highest K_{sat} and bulk

density, and the lowest moisture holding capacity. There was no difference in K_{sat} between uncoated sand with peat and artificially-coated sand. The laboratory method detected no difference in moisture holding capacity among uncoated sand with peat, naturally-, and artificially-coated sand with peat even though differences were detected throughout the maintenance phase using the Theta-probe (Table 4-57). In addition, Theta-probe volumetric moisture measurements were generally less than those observed using physical analytical methods but the same trends were observed. It should be noted that the laboratory method involves an equilibrium at 30 cm tension. By contrast, in the field turfgrass is withdrawing moisture, and there is evaporation. Therefore, the soil moisture could be lower, and differences among the root zone media could be better displayed. There was no difference in the bulk density between naturally- and artificially-coated sand.

Table 4-51 Influence of root zone media on clipping production during the Field Study I maintenance period.

Root zone	Days after planting						
	130	143	157	187	200	214	Total
	g m^{-2}						
Uncoated	1.6d†	1.9b	4.9b	19.9ab	12.7b	27.8b	68.8c
Unc. + Peat	3.0b	3.0a	7.7a	26.2ab	13.0b	32.0b	84.9b
Nat. + Peat	2.4c	2.1b	5.5b	19.1b	13.5b	31.6b	74.3bc
Art. + Peat	3.7a	3.6a	9.0a	28.1a	16.2a	39.1a	99.8a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-52 Influence of root zone media on potassium leaching as a function of time during maintenance field study I 2001 -2002.

Root zone	Days after planting								
	99	118	125	130	140	154	167	199	Total
	g m^{-2}								
Uncoated	1.62a†	0.05a	0.08a	0.05b	0.64c	0.42b	0.11b	0.04b	3.19b
Unc. + Peat	0.87a	0.05a	0.03a	0.13b	0.62c	0.18b	0.04b	0.02b	1.78b
Nat. + Peat	1.52a	0.09a	0.13a	0.53b	2.18b	0.40b	0.10b	0.04b	5.00b
Art. + Peat	1.91a	0.09a	0.20a	1.43a	6.75a	2.99a	1.43a	0.91a	15.71a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-53 Influence of root zone media on phosphorus leaching as a function of time during maintenance field study I 2001 -2002.

Root zone	Days after planting								
	99	118	125	130	140	154	167	199	Total
	g m^{-2}								
Uncoated	0.24a†	0.02a	0.04a	0.18a	0.25c	0.08b	0.03b	0.01a	0.91a
Unc. + Peat	0.44a	0.01a	0.02a	0.13a	0.88ab	0.17ab	0.04b	0.00a	1.60a
Nat. + Peat	0.65a	0.07a	0.06a	0.16a	1.41a	0.33a	0.18a	0.08a	2.94a
Art. + Peat	0.54a	0.02a	0.05a	0.16a	0.72bc	0.19ab	0.08ab	0.04a	1.81a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-54 Potassium and P leached during Field Study I maintenance relative to total K and P added and soil-test† K and P prior to Field Study I maintenance.

	K	P
	-------%-------	
Uncoated sand	65a‡	11b
Uncoated sand with peat	33a	20ab
Naturally-coated sand with peat	96a	34a
Artificially-coated sand with peat	56a	2b

† Soil-test K and P are based on 30 cm root zone.

‡ Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-55 Influence of root zone media on bermudagrass K uptake as a function of time during field study I maintenance.

Root zone	Days after planting						
	130	143	157	187	200	214	Total
	- - - - - - - - - - - - - - K mg m^{-2} - - - - - - - - - - - - -						- g m^{-2} -
Uncoated	22.0d†	23.5b	85.7c	269.6c	172.5b	363.7c	0.9c
Unc. + Peat	48.3b	46.1a	146.7b	373.8b	169.0b	485.4b	1.3b
Nat. + Peat	30.5c	28.6b	96.1c	267.8c	171.2b	433.0bc	1.0c
Art. + Peat	61.6a	55.0a	182.4a	478.3a	256.2a	636.1a	1.7a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-56 Influence of root zone media on bermudagrass P uptake as a function of time during field study I maintenance.

Root zone	Days after planting						
	130	143	157	187	200	214	Total
	- - - - - - - - - - - - - - P mg m^{-2} - - - - - - - - - - - - -						- g m^{-2} -
Uncoated	5.9b†	6.2b	23.6c	64.5c	46.4b	98.0c	0.2c
Unc. + Peat	13.7a	11.7a	42.4b	95.2ab	48.5b	128.2b	0.3b
Nat. + Peat	8.1b	7.3b	28.6c	73.5bc	55.5b	136.3b	0.3b
Art. + Peat	15.2a	13.5a	51.1a	113.4a	68.9a	166.4a	0.4a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-57 Influence of root zone media on volumetric soil moisture content on various dates during maintenance, field study I.

Root zone	Days after planting†					
	127	140	154	158	182	197
	- - - - - - - - - - - - L L^{-1} - - - - - - - - - - -					
Uncoated	0.06d‡	0.07c	0.07d	0.04c	0.10d	0.08c
Unc. + Peat	0.12c	0.12b	0.13c	0.11b	0.16c	0.12b
Nat. + Peat	0.13b	0.15a	0.14b	0.12b	0.18b	0.13b
Art. + Peat	0.15a	0.15a	0.16a	0.14a	0.21a	0.15a

†Irrigation was applied once daily.

‡Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-58 Selected chemical properties of root zone media upon completion of maintenance field study I.

Type	pH	CEC	Pa	Pw	K	Ca	Mg
		$cmol_c\ kg^{-1}$	- - - - - - - - -	mg L^{-1}	- - - - - - - - - -		
Uncoated Sand	6.8a †	0.0d	8.0b	2.4c	7.0b	135.6b	5.0b
Uncoated Sand and Peat	5.1c	5.5b	8.3b	4.1b	8.7b	173.8b	9.8b
Naturally-Coated Sand and Peat	5.2c	4.8c	12.7b	4.8b	7.8b	200.4b	21.1a
Artificially-Coated Sand and Peat	5.7b	6.2a	345.7a	16.3a	21.1a	399.7a	26.3a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-59 Physical properties of root-zone media upon termination of field study I.

Root-zone	K_{sat}	θ_V	φ_{BD}
	- -cm h^{-1}- -		
Uncoated	178.4a†	11.8b	1.76a
Uncoated with peat	120.6b	18.3a	1.65b
Naturally with peat	100.9c	20.0a	1.61c
Artificially with peat	112.7bc	20.0a	1.58c

†Any means followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Field Study II 2002

A second field study was conducted to reinvestigate the effect of coated sands and peat on turfgrass growth, P and K leaching/uptake, and root zone properties. In Field Study II treatments investigated remained the same but climate and fertilization differed from that of Field Study I. During Field Study II grow-in was initiated during early Summer and maintenance during Fall. In addition, K and P fertilization were reduced by 50 % during grow-in so as to better investigate root zone influence on turfgrass growth and nutrient retention.

Establishment

Selected physical properties of root-zone materials prior to establishment

The inclusion of peat had the greatest influence on root zone properties (Table 4-60). Uncoated sand had a K_{sat} greatly exceeding the accelerated range of 30-60 cm h^{-1} specified for putting green root zone mixes by the USGA (USGA Green Section Staff, 1993). There was no difference in K_{sat} among the other treatments. Similar K_{sat} results were measured prior to Field Study I establishment (Table 4-37). Peat increased volumetric water holding capacity (microspore space) and decreased bulk density. The inclusion of artificially-coated sand increased water holding capacity (θ_v) relative to uncoated sand (both with peat), whereas, an increase in water holding capacity was not detected between naturally-coated sand with peat and uncoated sand with peat. In the Field Study I establishment study, naturally-coated sand had a greater θ_v than uncoated sand with peat as determined by physical analysis (Table 4-37).

<u>Selected chemical properties of root zone materials prior to establishment</u>

Cation exchange levels and soil-test values were measured prior to establishment (Table 4-61). Soil-test values were generally greater than those measured prior to Field Study I (Table 4-38). It is important to note that while new root zone material was added to each plot, it was incorporated with existing root zone material (see materials and methods), thereby accounting for the increase in soil-test values.

Uncoated sand with peat had the lowest pH, with no difference in pH between uncoated sand, naturally-coated sand with peat, and artificially-coated sand with peat. The pH values were generally higher than those measured at the completion of Field Study I maintenance (Table 4-58) and generally reflect those values measured prior to Field Study I establishment (Table 4-38).

Soil-test P determined prior to Field Study II were generally greater than Field Study I preconstruction levels (Table 4-61). Artificially-coated sand had the highest Pa with no difference in Pa measured among the other treatments. In addition, artificially-coated sand had more Pw than the other treatments. More Pw was measured in naturally-coated sand than uncoated sand and uncoated sand with peat. There was no difference in Pw between uncoated sand and uncoated sand with peat.

Soil-test K levels determined prior to Field Study II were generally like those levels measured prior to Field Study I (Table 4-38). Similar to previous soil-test K results, artificially-coated sand with peat had the highest soil-test K. Artificially-coated sand with peat soil-test K, however, was less than that measured prior to Field Study I (Table 4-38) perhaps as a result of mixing and dilution with existing artificially-coated

sand with peat material. There was no difference in soil-test K among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat.

Because of mixing with existing root zone material, CEC values better resembled values measured following Field Study I maintenance (Table 4-58) than preconstruction Field Study I (Table 4-38). CEC ranged from 0.0 - 6.2 cmol kg^{-1} with artificially-coated sand with peat having the highest CEC value and uncoated sand the lowest. Unlike CEC values determined prior to Field Study I, the CEC of uncoated sand with peat was greater than that of naturally-coated sand with peat at the start of Field Study II probably because of mixing with existing root zone material during reconstruction of experimental plots.

'Tifdwarf' coverage during establishment

'Tifdwarf' establishment was increased by the inclusion of peat and artificially-coated sand (Table 4-62). Root zones with peat reached approximately 100 % coverage several weeks before the uncoated sand treatment. The increase in 'Tifdwarf' coverage in the presence of peat likely resulted from increased moisture retention associated with properties of peat (McCoy, 1991, 1992; Bigelow, 2000). Just as peat served to increase establishment, the presence of artificially-coated sand further increased establishment beyond that of uncoated sand with peat and naturally-coated sand with peat. 'Tifdwarf' growing in the artificially-coated sand with peat root zone reached almost full coverage by 34 DAP while uncoated sand with peat and naturally-coated sand with peat required during approximately 55 DAP. In general, there was no difference between uncoated sand with peat and naturally-coated sand with peat.

Many similarities in 'Tifdwarf' establishment exist between Field Study I (Table 4-40) and Field Study II (Table 4-62) despite only half the P and K fertilization in Field Study II. In both studies the inclusion of artificially-coated sand increased establishment rate. The inclusion of peat also increased establishment rate. The slowest establishment was observed in the uncoated sand root zone mix. In both studies there was no difference between uncoated sand with peat and naturally-coated sand with peat. Overall establishment rate, however, was more rapid in Field Study II because of the early Summer grow-in period versus the Fall grow-in period of Field Study I.

Clipping production during establishment

Clipping production during establishment reflected establishment rate observations (Table 4-62) in that the inclusion of peat and artificially-coated sand influenced 'Tifdwarf' growth (Table 4-63). The presence of artificially-coated sand increased clipping production relative to uncoated sand from 28 to 83 DAP. In addition, the inclusion of peat increased clipping production relative to uncoated sand from 34 to 83 DAP. In general, the inclusion of peat and artificially-coated sand also increased clipping production during Field Study I establishment.

The inclusion of artificially-coated sand increased clipping production over the treatments with peat alone (Table 4-63). Artificially-coated sand with peat increased clipping production relative to uncoated sand with peat and naturally-coated sand with peat 28 to 55 DAP. An increase in clipping production beyond 55 DAP was not observed likely because there was little difference in coverage between uncoated sand with peat, naturally-coated sand with peat, and artificially-coated sand with peat from 55 to 69 DAP

(Table 4-62). In general, during Field Study I establishment there was little difference in clipping production between uncoated sand with peat and artificially-coated sand with peat because of the heavy fertilization and the poorer late season grow-in conditions (Table 4-41).

There was no difference in clipping production between naturally-coated sand with peat and uncoated sand with peat during the establishment period (Table 4-63).

The inclusion of peat and artificially-coated sand increased total clipping production (Table 4-63). Peat increased total clipping production approximately 49 % relative to uncoated sand without peat. The inclusion of artificially-coated sand increased total clipping production 89 % and 27 % relative to uncoated sand and uncoated sand with peat. In the Phase II glasshouse study, the presence of peat and artificially-coated sand also increased total clipping production relative to uncoated sand.

Potassium leached during establishment

The inclusion of artificially-coated sand had the greatest impact on K leached during establishment (Table 4-64). The addition of artificially-coated sand to uncoated sand with peat increased K leached relative to uncoated sand, uncoated sand with peat, and naturally-coated sand. More K leaching from artificially-coated sand probably was due to the high soluble K content of artificially-coated sand (Table 4-61). The inclusion of peat to uncoated sand and naturally-coated sand did not decrease K leaching relative to uncoated sand alone except at 69 and 90 DAP. In addition, the presence of natural sand grain coatings did not reduce K leached. In Field Study I the inclusion of peat & presence of naturally-coated sand didn't decrease K leaching during establishment (Table 4-42).

The addition of artificially-coated sand increased total K leached while the inclusion of peat and presence of naturally-coated sand did not reduce total K leached relative to uncoated sand (Table 4-64). There was no difference in total K leached among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat despite wide differences in CEC (Table 4-61). More than one third of applied K leached from uncoated sand, uncoated sand with peat, and naturally-coated sand with peat. In Field Study I there was no difference in total K leached among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat (Table 4-42) with more than one third of applied K lost.

Phosphorus leached during establishment

Substantial P leached from all root zone media during establishment (Table 4-65). Relatively large quantities of P leached from all treatments, especially during the first 47 DAP in which approximately 58 cm of rainfall was recorded (Table 4-65). In addition, from 3 to 47 DAP percolate P concentration of all treatments exceeded 0.3 mg L^{-1} (Table A-20). While P leaching decreased from 55 to 76 DAP when rainfall rates decreased, high P losses were observed 83 and 90 DAP when over 8 cm of rainfall was recorded.

The inclusion of peat in uncoated sand decreased total P leached relative to uncoated sand alone (Table 4-65) during establishment. Furthermore, less total P leached from uncoated sand with peat than naturally-coated sand and artificially-coated sand with peat during establishment. Approximately 35 % of applied P leached from uncoated sand, naturally-coated sand with peat, and artificially-coated sand with peat versus 23 %

for uncoated sand with peat. In Field Study I, no difference in total P leached among treatments was not observed perhaps because of high P fertilization which may have masked differences among the treatments (Table 4-43).

Relative K and P leached during establishment

More total K leached from artificially-coated sand with peat during establishment, however, when differences in inherent K content were accounted for, no differences were observed among artificially-coated sand with peat, uncoated sand, uncoated sand with peat, and naturally-coated sand with peat (Table 4-66). Moreover, there was no difference in relative K leached among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat during establishment.

Differences in relative P leached were observed during establishment (Table 4-66). P leaching, relative to the amount of added and inherent P in the root zone, was greatest from uncoated sand and least from artificially-coated sand. During establishment, less total P leached from uncoated sand with peat than uncoated sand and naturally-coated sand (Table 4-65) with the same observations made with regard to relative P leached during establishment. Similar trends in relative P leached were observed during Field Study I establishment (Table 4-44).

Potassium uptake during establishment

The inclusion of peat and artificially-coated sand increased K uptake during establishment (Table 4-67). From 34 to 76 DAP the addition of peat to uncoated and naturally-coated increased K uptake. The increased K uptake from uncoated and naturally-coated sand with peat is the result of both increased clipping production (Table

4-63) and increased tissue K concentration (Table A-21). The inclusion of artificially-coated sand in uncoated sand with peat further increased K uptake relative to uncoated sand from 28 to 83 DAP during establishment. The ability of artificially-coated sand to increase both clipping production (Table 4-63) and tissue K concentration (Table A-21) together improved K uptake during establishment relative to uncoated sand. In Field Study I the inclusion of peat and artificially-coated sand also increased K uptake during establishment (Table 4-46).

In general, there was no difference in K uptake between uncoated sand with peat and naturally-coated sand with peat (Table 4-67) during establishment. Only on 69 and 76 DAP did uncoated sand with peat increase K uptake over that of naturally-coated sand with peat. Increased K uptake from uncoated sand with peat 69 and 76 DAP relative to naturally-coated sand with peat was the result of a combination of increased clipping production and tissue K concentration (Table A-21) even though neither observation was statistically significant alone. In Field Study I, uncoated sand with peat increased K uptake relative to naturally-coated sand with peat throughout establishment (Table 4-46).

The inclusion of artificially-coated sand in uncoated sand with peat increased K uptake relative to uncoated sand with peat and naturally-coated sand with peat through much of establishment (Table 4-67). From 28 to 62 DAP greater K uptake was observed from artificially-coated sand with peat than from either uncoated sand with peat or naturally-coated sand with peat. Furthermore, 69 and 76 DAP the improvement in K uptake relative to naturally-coated sand continued. There was no difference between uncoated sand with peat and artificially-coated sand with peat from 69 to 90 because there

was no difference in clipping production during the late stages of establishment. Higher tissue K concentration from 'Tifdwarf' establishing in artificially-coated sand with peat than uncoated sand with peat was observed from 28 to 41 DAP (Table A-21). The elevated soil K content of artificially-coated sand with peat likely provided an immature root system readily available K, thereby contributing to the increase in K uptake during the early stages of establishment.

While there was no difference in total K uptake between uncoated sand with peat and naturally-coated sand with peat, the addition of artificially-coated sand to uncoated sand with peat increased total K uptake relative to uncoated sand, uncoated sand with peat, and naturally-coated sand with peat (Table 4-67). Readily available K (Table 4-61), coupled with greater moisture retention (Table 4-70), accelerated growth (Table 4-63) and increased tissue K concentration (Table A-21) of 'Tifdwarf' establishing in artificially-coated sand with peat. Approximately 12 % of applied K was taken up from uncoated sand with peat and naturally-coated sand with peat. Uncoated sand had the lowest total K uptake compromising only 7 % of applied K. Poor nutrient (Table 4-61) and moisture retention (Table 4-70) characteristics of uncoated sand resulted in slower growth (Table 4-63) and lower tissue K concentration (Table A-21) negatively impacting total K uptake during establishment.

Phosphorus uptake during establishment

The inclusion of peat and artificially coated sand increased P uptake through much of establishment (Table 4-68). From 34 to 76 DAP peat increased P uptake because of increased clipping production (Table 4-63) and to some extent increased tissue

P concentration (Table A-22). Increased P uptake relative to uncoated sand was observed from the presence of artificially-coated sand from 28 to 83 DAP. Artificially-coated sand with peat increased tissue P concentration relative to uncoated sand 28 to 47 DAP (Table A-22). The addition of peat and artificially-coated sand to uncoated sand increased P uptake throughout Field Study I establishment (Table 4-47).

There was no difference in P uptake between uncoated sand with peat and naturally-coated sand with peat during establishment (Table 4-68). Since the presence of naturally-coated sand did not increase either clipping production (Table 4-63) or tissue P concentration (Table A-22), greater P uptake from naturally-coated sand relative to uncoated sand with peat was not observed. The negative influence of naturally-coated sand with peat on P uptake observed in Field Study I establishment (Table 4-47) was not observed during Field Study II establishment.

The addition of artificially-coated sand to uncoated sand with peat increased P uptake early in establishment relative to uncoated sand with peat and naturally-coated sand with peat (Table 4-68). From 28 to 62 DAP greater P uptake was observed from artificially-coated sand with peat than uncoated sand with peat and naturally-coated sand with peat because of increased clipping production (Table 4-63) and tissue P concentration (Table A-22). From 69 to 90 DAP no difference was observed.

The inclusion of artificially-coated sand and peat increased total P uptake during establishment (Table 4-68). The lowest total P uptake was observed in uncoated sand. There was no difference in total P uptake between uncoated sand with peat and naturally-

coated sand with peat. In Field Study I establishment uncoated sand with peat increased total P uptake 33 % over that of naturally-coated sand with peat (Table 4-47). Artificially-coated sand increased total P uptake 35 % relative to uncoated sand with peat and naturally-coated sand with peat. Increased total P uptake resulted because of the combination of increased clipping production (Table 4-62) and tissue P concentration (Table A-22) of 'Tifdwarf' growing in the P rich artificially-coated sand root zone. By comparison, in Field Study I establishment, when twice as much fertilizer P was applied, there was no difference between uncoated sand with peat and artificially-coated sand with peat (Table 4-40).

Relative K and P uptake during establishment

Potassium uptake, relative to the amount of K added and inherent in the root zone, was greatest in the presence of peat (Table 4-69). Both uncoated sand with peat and naturally-coated sand with peat had greater relative K uptake than uncoated sand alone. Although total K uptake during establishment was greatest from artificially-coated sand with peat (Table 4-67), relative K uptake was the least from artificially-coated sand with peat.

Greater P uptake, relative to added and inherent root zone quantity, was greatest from uncoated sand with peat (Table 4-69). There was no difference in relative P uptake between uncoated sand alone and naturally-coated sand with peat (Table 4-69), while total P uptake was greater from naturally-coated sand with peat than uncoated sand during

establishment. Even though total P uptake was the greatest from artificially-coated sand with peat during establishment (Table 4-68), the lowest relative P uptake was observed from artificially-coated sand with peat (Table 4-69).

Volumetric moisture content during establishment

The addition of peat and artificially-coated sand increased soil moisture content in the field during establishment (Table 4-70). Artificially-coated sand with peat had the highest moisture content during establishment and uncoated sand had the lowest moisture content. Naturally-coated sand with peat had greater soil moisture than uncoated sand with peat during the early stages of establishment but a difference between the two treatments was not detected by the end of the establishment period.

Soil moisture values measured during establishment using the Theta-probe were less than those determined using physical analysis techniques (Table 4-60). This probably occurred because in the laboratory the moisture content was measured as a 30 cm negative pressure equilibrium value, whereas in the field moisture probably was lower due both to evaporation and plant uptake. Theta-probe measurements in the field, however, were similar to physical analysis measurements in the lab in terms of identifying relative differences in soil moisture among the treatments. Both techniques showed that artificially-coated sand with peat had the highest soil moisture content, the inclusion of peat increased soil moisture, and that uncoated sand had the lowest soil moisture.

Selected chemical properties of root zone mixes at the conclusion of establishment

The inclusion of peat and artificially-coated sand influenced soil pH (Table 4-71). Poorly buffered uncoated sand had the highest soil pH upon completion of establishment. There was no difference in soil pH among uncoated sand with peat, naturally-coated sand with peat, and artificially-coated sand with peat. Soil pH of all treatments generally decreased during establishment (Table 4-61, 4-71).

The inclusion of artificially-coated sand increased soil Pa and Pw upon completion of establishment (Table 4-71). There was no difference in soil Pa or Pw among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat. Following Field Study I establishment, artificially-coated sand with peat also had the highest soil Pa and Pw with no difference detected between uncoated sand, uncoated sand with peat, and naturally-coated sand with peat (Table 4-50). In both field studies, high soil P was due to the inherent P content of artificially-coated sand.

The inclusion of artificially-coated sand increased soil K (Table 4-71). There was, however, no difference among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat despite far greater CEC of uncoated sand with peat and naturally-coated sand with peat relative to uncoated sand. Inherent K content and CEC contributed to greater soil-test K of artificially-coated sand. In Field Study I establishment uncoated sand had lower soil-test K than uncoated sand with peat and artificially-coated sand with peat (Table 4-50).

Table 4-60 Physical properties of root-zone media prior to construction field study II

Root-zone	K_{sat}	θ_V	φ_{BD}
	- -cm h^{-1}- -		- g cm^{-3} -
Uncoated	85.0a†	0.10c	1.76a
Uncoated with peat	47.5b	0.14b	1.70b
Naturally with peat	48.7b	0.15b	1.64c
Artificially with peat	42.6b	0.17a	1.61c

†Any means followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-61 Selected chemical properties of root zone media used in field study II prior to construction.

Root zone	pH	CEC	Pa	Pw	K	Ca	Mg
		$cmol_c\ kg^{-1}$	- - - - - - - - - -	mg L^{-1}	- - - - - - - - -		
Uncoated Sand	8.2a†	0.0d	2.6b	0.9c	3.8b	306.2c	3.3b
Uncoated Sand and Peat	6.0b	5.6b	5.6b	2.1c	4.8b	337.4c	6.8b
Naturally-Coated Sand and Peat	7.9a	4.8c	17.0b	5.6b	4.3b	517.6b	75.3a
Artificially-Coated Sand and Peat	8.4a	6.2a	332.3a	14.1a	208.5a	661.4a	89.5a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-62 Influence of root zone media on 'Tifdwarf' coverage as a function of time after planting field study II 2002.

Root zone	Days after planting								
	13	19	26	34	40	47	55	62	69
	%								
Uncoated	8.8b†	8.8c	22.5c	30.0c	38.8d	35.0c	53.8b	80.0b	92.5b
Unc. + Peat	12.5b	18.8b	46.2b	61.2b	72.5c	92.5b	98.8a	100.0a	100.0a
Nat. + Peat	11.5b	18.8b	46.2b	62.5b	78.8b	95.0b	100.0a	100.0a	100.0a
Art. + Peat	26.2a	37.5a	77.5a	95.0a	98.8a	100.0a	100.0a	100.0a	100.0a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-63 Influence of root zone media on clipping production as a function of time after planting field study II 2002.

Root zone	Days after planting									
	28	34	41	47	55	62	69	76	83	90	Total
	g m^{-2}										
Uncoated	1.2b†	0.5c	0.5c	0.8c	1.0c	2.6b	12.1b	12.4b	22.4b	30.5a	84.0c
Unc. + Peat	2.7b	1.7b	3.4b	3.3b	4.3b	5.9a	17.4a	19.0a	31.1a	37.1a	125.9b
Nat. + Peat	3.0b	1.3b	4.0b	3.1b	4.9b	5.4a	15.7ab	17.2a	30.2a	37.9a	122.7b
Art. + Peat	11.1a	4.2a	10.8a	7.1a	6.9a	6.7a	16.6ab	19.8a	36.4a	40.0a	159.8a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-64 Influence of root zone media on potassium leaching as a function of time after planting field study II 2002.

Root zone	Days after planting														
	3	7	12	18	29	34	40	47	55	62	69	76	83	90	Total
	$g\ m^{-2}$														
Uncoated	1.78ab†	1.70b	0.50b	1.59b	0.57b	0.45b	0.11b	0.27b	0.13a	0.25ab	0.20b	0.09a	0.54b	0.79a	8.98b
Unc. + Peat	0.60b	0.85b	0.37b	1.79b	1.41b	0.95b	0.10b	0.13b	0.07a	0.09b	0.03c	0.02a	0.32b	0.12b	6.87b
Nat. + Peat	0.39b	0.57b	0.33b	1.16b	0.95b	0.66b	0.11b	0.13b	0.08a	0.20ab	0.04c	0.01a	0.22b	0.10b	4.97b
Art. + Peat	2.31a	3.72a	1.49a	5.10a	3.76a	3.45a	0.54a	0.72a	0.29a	0.49a	0.39a	0.11a	1.59a	0.59ab	24.54a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-65 Influence of root zone media on phosphorus leaching as a function of time after planting field study II 2002.

Root zone	Days after planting														
	3	7	12	18	29	34	40	47	55	62	69	76	83	90	Total
	$g\ m^{-2}$														
Uncoated	0.45a†	0.46a	0.15ab	0.39b	0.23b	0.31b	0.08b	0.15b	0.02bc	0.13a	0.06a	0.01a	0.49ab	0.40a	3.35a
Unc. + Peat	0.16bc	0.21a	0.11b	0.36b	0.30b	0.35b	0.08ab	0.17b	0.01c	0.02b	0.02a	0.00a	0.23c	0.13b	2.16b
Nat. + Peat	0.34ab	0.39a	0.29a	0.63a	0.39a	0.43ab	0.14a	0.26a	0.03ab	0.07ab	0.06a	0.01a	0.27bc	0.25ab	3.56a
Art. + Peat	0.11c	0.28a	0.12ab	0.46ab	0.40a	0.54a	0.12ab	0.26a	0.04a	0.09ab	0.05a	0.03a	0.57a	0.18ab	3.24a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-66 Potassium and P leached during Field Study II establishment relative to total K and P added and soil-test† K and P prior to Field Study II establishment.

	K	P
	-------%--------	
Uncoated sand	45a‡	29a
Uncoated sand with peat	34a	17c
Naturally-coated sand with peat	25a	23b
Artificially-coated sand with peat	32a	3d

† Soil-test K and P are based on 30 cm root zone.

‡ Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-67 Influence of root zone media on potassium uptake as a function of time after planting field study II 2002.

Root zone	Days after planting										
	28	34	41	47	55	62	69	76	83	90	Total
	K mg m^{-2}										- g m^{-2} -
Uncoated	3.4b†	1.8c	2.2c	7.6c	9.7c	31.6c	127.5c	146.9c	364.0b	510.0a	1.2c
Unc. + Peat	13.3b	16.8b	32.9b	45.3b	44.1b	75.3b	269.0a	280.0a	573.9a	679.6a	2.0b
Nat. + Peat	15.6b	18.6b	38.2b	38.8b	48.1b	65.8b	209.3b	232.1b	497.4ab	703.5a	1.9b
Art. + Peat	123.9a	63.3a	157.6a	99.4a	88.2a	110.0a	274.0a	307.7a	664.3a	794.6a	2.7a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-68 Influence of root zone media on phosphorus uptake as a function of time after planting field study II 2002.

Root zone	Days after planting										
	28	34	41	47	55	62	69	76	83	90	Total
	P mg m^{-2}										- g m^{-2} -
Uncoated	2.2b†	0.7c	1.1c	2.8c	4.0c	11.2c	43.0b	52.8c	114.0b	148.9a	0.4c
Unc. + Peat	6.7b	5.4b	12.3b	17.6b	17.7b	24.0b	87.3a	95.7a	180.8a	207.0a	0.6b
Nat. + Peat	8.0b	5.2b	13.4b	15.1b	20.2b	22.9b	73.4a	84.3b	171.0ab	209.6a	0.6b
Art. + Peat	37.7a	17.4a	47.4a	34.1a	29.1a	34.0a	82.2a	101.7a	204.0a	235.0a	0.8a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-69 Potassium and P uptake during Field Study II establishment relative to total K and P added and soil-test† K and P prior to Field Study II establishment.

	K	P
	------- % -------	
Uncoated sand	6.0b‡	3.3b
Uncoated sand with peat	10.0a	5.2a
Naturally-coated sand with peat	9.3a	4.0b
Artificially-coated sand with peat	3.4c	0.7c

† Soil-test K and P are based on 30 cm root zone.

‡ Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-70 Influence of root zone media on soil moisture content as a function of time after planting field study II.

Root zone	Days after planting†	
	28	76
	- - Volumetric moisture content - -	
Uncoated	0.04d‡	0.05c
Unc. + Peat	0.07c	0.08b
Nat. + Peat	0.09b	0.08b
Art. + Peat	0.11a	0.10a

†Irrigation was applied twice daily.

‡Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-71 Selected chemical properties of root zone media upon completion of field study II establishment 2002.

Root zone	pH	Pa	Pw	K	Ca	Mg
		- - - - - - - - - - mg L^{-1} - - - - - - - - -				
Uncoated Sand	6.8a†	11.2b	4.1b	6.1b	57.7c	3.3b
Uncoated Sand and Peat	5.2bc	8.3b	4.4b	7.0b	49.0c	3.7b
Naturally-Coated Sand and Peat	5.5b	7.2b	3.8b	7.0b	86.6b	15.5a
Artificially-Coated Sand and Peat	5.2c	323.0a	22.2a	18.1a	226.1a	14.9a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Maintenance

Clipping production during maintenance

Clipping production was influenced by the inclusion of artificially-coated sand and in part, to peat amended to uncoated sand during maintenance (Table 4-72). The addition of peat increased clipping production 97, 111, and 125 DAP relative to uncoated sand. The effect of root zone media on clipping production during Field Study I maintenance was similar to the effect in Field Study II maintenance in that the inclusion of peat to uncoated sand increased clipping production in the early stages of maintenance with no difference occurring during the late stages of maintenance (Table 4-51). The addition of artificially-coated sand to uncoated sand with peat, however, increased clipping production over uncoated sand more consistently than uncoated sand with peat alone with an increase observed 97, 111, 125, 132, 139, 166, and 180 DAP during maintenance. In both Field Study I and Field Study II maintenance the presence of artificially-coated sand increased clipping production relative to uncoated sand both early and late in the maintenance period. The presence of naturally-coated sand, however, did not increase clipping production relative to uncoated sand in either study.

The inclusion of peat and artificially-coated sand to uncoated sand increased total clipping production during maintenance (Table 4-72). Peat added to uncoated sand increased total clipping production by 13% over uncoated sand alone. Further increases were observed when artificially-coated sand was amended to uncoated sand with peat. Total clipping production from uncoated sand with peat was increased 8% by the addition of artificially-coated sand. In Field Study I, the inclusion of artificially-coated sand

increased total clipping production by 18% relative to uncoated sand with peat. Naturally-coated sand had the lowest total clipping production during maintenance. In Field Study I there was no difference between naturally-coated sand with peat and uncoated sand alone (Table 4-51).

K leached during maintenance

Because of the high K content of artificially-coated sand, its inclusion increased K leached during maintenance (Table 4-73). With the exception of 97 DAP there was no difference in K leached from artificially-coated sand with peat and uncoated sand. There was no difference, however, in K leached among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat during maintenance.

The presence of artificially-coated sand increased total K leached during maintenance (Table 4-73). There was no difference in total K leached among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat.. In Field Study I maintenance, total K leached also was greater from artificially-coated sand with peat (Table 4-52). In addition there was no difference in total K leached among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat during Field Study I maintenance (Table 4-52).

P leached during maintenance

Following the cessation of P fertilization at 90 DAP, P leaching generally decreased with time during the maintenance period (Table 4-74). While percolate P concentrations decreased with time, concentrations exceed 0.3 mg L^{-1} throughout the maintenance period (Table A-24). With two exceptions (97 and 180DAP), there were no

differences among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat. More P leached from artificially-coated sand than uncoated sand and uncoated sand with peat from 118 to 173 DAP. In addition, more P leached from artificially-coated sand than naturally-coated sand from 132 to 173 DAP. Percolate P concentrations were greatest from artificially-coated sand from 139 - 180 DAP (Table A-24).

The greatest total P leached from artificially-coated sand with peat during maintenance (Table 4-74). High P content of artificially-coated sand served as a source of soluble P throughout the maintenance period contributing to P losses. There was no difference in total P leached from uncoated sand, uncoated sand with peat, and naturally-coated sand with peat. In Field Study I maintenance there was no difference in total P leached among any of the treatments (Table 4-53). Because no P was applied during Field Study II maintenance differences among treatments were observed.

Relative K and P leached during maintenance

Despite greater total K leached from artificially-coated sand with peat during maintenance, there was no differences in relative K leached among the treatments (Table 4-75). Similar results were observed during Field Study I maintenance.

Phosphorus leaching, relative to inherent soil P, was the least from the root zone amended with peat and artificially-coated sand (Table 4-75). The lowest relative amount of P leached was observed from artificially-coated sand with peat. Thus the artificially-coated sand with peat treatment is a high P content root zone, but P leaching relative to P content is minimal.

K uptake during maintenance

The inclusion of peat and artificially-coated sand to uncoated sand increased K uptake during the early stages of maintenance (97 - 125 DAP) (Table 4-76). There was no difference, however, between uncoated sand and uncoated sand with peat from 132-173 DAP, perhaps because of decreased soil K. In general, the inclusion of artificially-coated sand increased K uptake throughout the maintenance period because of greater soil K content. The presence of natural sand grain coatings did not increase K uptake relative to uncoated sand, and on three sampling dates (104, 153, 160 DAP) less K uptake was observed.

The addition of peat and artificially-coated sand to uncoated sand increased total K uptake during the maintenance period (Table 4-76). The presence of naturally-coated sand did not increase total K uptake relative to uncoated sand alone. During Field Study I maintenance, the inclusion of peat and artificially-coated sand also increased total K uptake.

P uptake during maintenance

When artificially-coated sand was added to uncoated sand with peat, P uptake was increased over that of uncoated sand alone during maintenance (Table 4-77). The addition of only peat to uncoated sand increased P uptake, but the effect was observed to a lesser extent than that occurring due to the inclusion of artificially-coated sand as well. The combination of high P content and increased moisture retention increased dry matter production and P uptake of 'Tifdwarf' growing in artificially-coated sand relative to uncoated sand alone through much of the maintenance period.

Total P uptake was increased by the inclusion of peat and artificially-coated sand to uncoated sand (Table 4-78). Peat and artificially-coated sand increased total P uptake by 12 % and 38 % relative to uncoated sand alone. Increased total P uptake is best related to increased dry matter production from the addition of peat and artificially-coated sand.

Phosphorus uptake was greater from artificially-coated sand with peat than from uncoated sand with peat during maintenance (Table 4-78). In Field Study I maintenance artificially-coated sand also resulted in greater total P uptake than uncoated sand with peat (Table 4-56). The naturally-coated sand with peat had the smallest quantity of total P uptake during maintenance.

Relative K and P uptake during maintenance

Relative K uptake generally increased during maintenance in comparison to relative K uptake during establishment (Table 4-79, 4-66). Furthermore, relative K uptake from uncoated sand and uncoated sand with peat exceeded 100%, because of mobilization of K from stolons and rhizomes to leaf tissue which also may indicate immanent K deficiency. On the other hand, relative K uptake from artificially-coated sand was approximately half that of uncoated sand and uncoated sand with peat indicating a greater ability of the artificially-coated sand treatment to supply K as overall soil K levels decreased during maintenance, because considerable K remained in the artificially-coated sand with peat for possible future uptake.

Relative P uptake also generally increased during maintenance. Less relative P uptake was observed from uncoated sand than uncoated sand with peat and naturally-coated sand with peat. The lowest relative P uptake was observed from artificially-coated sand with peat.

Soil moisture content during maintenance

Soil moisture content was measured twice approximately 12 h following early morning irrigation. Peat and artificially-coated sand increased soil moisture relative to uncoated sand during the most stressful part of the day (Table 4-80). The presence of naturally-coated sand did not increase soil moisture content relative to that of uncoated sand with peat. The inclusion of artificially-coated sand did, however, increase soil moisture over that of uncoated sand with peat.

Selected chemical properties of root zone materials at the conclusion of the maintenance

Because the ammonium-based N fertilization was reduced and the irrigation water was calcarious, the pH of treatments generally increased during the maintenance period (Table 4-81). Uncoated sand had the highest pH following establishment (Table 4-61and continued to have the highest pH at the end of the maintenance period. The inclusion of peat increased the buffering capacity of uncoated sand which resulted in a lower soil pH. The acidic property of peat and buffer capacity appear to have diminished with time, in that the pH of uncoated sand with peat generally increased during maintenance relative to the end of establishment (Table 4-71). The pH of naturally-coated sand with peat was less than that of uncoated sand and uncoated sand with peat, but also increased with time

following establishment (Table 4-71). Artificially-coated sand with peat had the lowest pH at the end of maintenance and remained most similar to that following establishment (Table 4-71).

The CEC of treatments were generally slightly higher (Table 4-81) than at the beginning of the study (Table 4-66) perhaps as soil pH and organic matter content increased. The CEC of naturally-coated sand with peat, however, did not change during the study. Artificially-coated sand with peat had the highest CEC and was the only treatment with a CEC value $\geq$ 6 cmol kg^{-1}, the benchmark value suggest for sand-based root zone mixes (Petri and Petrovic, 2001). The inclusion of peat to uncoated sand continued to have a marked influence on CEC, with the CEC of uncoated sand with peat substantially higher than that of uncoated sand alone.

Without P fertilization during maintenance, soil Pa of all treatments decreased (Table 4-81) relative to the end of establishment (Table 4-71). There was no difference in Pa or Pw among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat. Artificially-coated sand with peat had the highest Pa and Pw because of inherent P content and P retention characteristics.

Potassium fertilization ceased following establishment as well, and soil K generally decreased during maintenance (Table 4-81). Artificially-coated sand had the highest soil K because of inherent K and retention characteristics at the end of maintenance. Despite variations in CEC there was no difference in soil K among uncoated sand, uncoated sand

with peat, and naturally-coated sand with peat. Likewise, there was no difference in soil K among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat following establishment (Table 4-71).

Selected physical properties of root zone materials in undisturbed cores at the conclusion of maintenance

Uncoated sand had the highest K_{sat} at the end of maintenance (Table 4-82). The inclusion of peat slowed K_{sat}. Uncoated sand with peat had a higher K_{sat} than either naturally-coated sand with peat or artificially-coated sand with peat. All treatments exceeded the accelerated range of 30-60 cm h^{-1} specified for putting green root zone mixes by the USGA (USGA Green Section Staff, 1993) but the undisturbed cores was not compacted by the technique specified by the USGA for laboratory analysis and little thatch accumulation was observed.

The addition of peat and sand grain coatings increased moisture retention (Table 4-82). Uncoated sand alone had the lowest moisture holding capacity. The addition of artificially-coated sand to uncoated sand with peat increased moisture retention relative to that of uncoated sand with peat. In the laboratory, naturally-coated sand with peat had greater soil moisture than uncoated sand with peat, whereas, no difference between the two treatments was detected in the field using Theta-probe during maintenance (Table 4-80).

Rubidium leached during Field Study II

Rubidium leaching and retention were studied to indicate how the treatments affected cation leaching and retention, because fertilizer K could not be distinguished

from K inherent to the root zone media. Rubidium leaching (Table 4-83) was influenced by the CEC of root zone mixes (Table 4-81). The presence of Rb was first detected 7 days after application (DAA) in percolate water leached from uncoated sand. At 14 DAA, traces of Rb^{1+} were detected in percolate water leached from uncoated sand with peat and artificially-coated sand with peat, but there was no difference in Rb leached among uncoated sand with peat, naturally-coated sand with peat, and artificially-coated sand with peat. By 21 DAA, Rb was observed in percolate water of all treatments except artificially-coated sand with peat, with more Rb leached from uncoated sand and uncoated sand with peat than naturally-coated sand with peat and artificially-coated sand with peat. Less Rb leaching from naturally-coated sand with peat than uncoated sand with peat may be due to the ability of the natural clay coating of naturally-coated sand with peat to better retain monovalent cations than the sphagnum peat associated with uncoated sand with peat. Bell (1959) demonstrated that trivalent and divalent cations were absorbed much more strongly by Sphagnum than monovalent cations. From 28 to 42 DAA, fewer differences in Rb leaching were observed among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat as Rb levels in root zone decreased with time.

The inclusion of peat and artificially-coated sand influenced total Rb leached during the study period (Table 4-83). The greatest quantity of Rb leached from uncoated sand. Uncoated sand with peat and naturally-coated sand with peat decreased total Rb leached relative to uncoated sand alone because of higher CEC (Table 4-81). The smallest quantity of Rb leached from artificially-coated sand with peat which had the

highest CEC of any treatment (Table 4-81). Thus, even though the most K leaching was observed in the artificially-coated sand (Table 4-73), the Rb study suggested that a monovalent cation applied as fertilization can be retained by that root zone media.

Effect of root zone mixture on soil Rb

The inclusion of artificially coated sand had the greatest influence on retention of soil Rb in the top 10 cm of the root zone mixture (Table 4-84). While the addition of peat to the root zone mixture decreased Rb leached (Table 4-83), there was no difference in soil Rb among uncoated sand, uncoated sand with peat, and naturally-coated sand with peat in the top 10 cm of root zone. Artificially-coated sand with peat, however, decreased Rb leached (Table 4-83) and increased soil Rb (Table 84).

Table 4-72 Influence of root zone media on clipping production as a function of time after planting field study II 2002 maintenance.

Root zone	Days after planting													
	97	104	111	118	125	132	139	146	153	160	166	173	180	Total
	$g\ m^{-2}$													
Uncoated	22.5b†	27.2a	17.6b	18.6ab	12.7b	10.4bc	8.7bc	14.6ab	10.8a	13.0a	6.1bc	6.6ab	4.1b	173.0c
Unc. + Peat	27.0a	29.5a	20.0a	21.2a	15.3a	12.4ab	9.7ab	15.4ab	11.0a	13.5a	7.2ab	8.5ab	4.8ab	195.4b
Nat. + Peat	22.7b	22.0b	16.0b	15.9b	12.7b	9.0c	7.0c	11.9b	7.0b	8.6a	5.1c	6.0b	4.0b	147.9d
Art. + Peat	27.0a	28.5a	20.4a	21,4a	16.7a	14.4a	11.6a	18.9a	12.2a	15.2a	8.3a	9.9a	6.0a	210.6a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-73 Influence of root zone media on potassium leaching as a function of time after planting field study II 2002 maintenance.

Root zone	Days after planting											
	97	104	111	118	132	139	153	160	166	173	180	Total
	g m^{-2}											
Uncoated	0.15b†	0.00a	0.02ab	0.01ab	0.17b	0.09ab	0.27ab	0.16ab	0.11ab	0.06a	0.03a	1.08b
Unc. + Peat	0.06b	0.00a	0.02b	0.01b	0.02b	0.01b	0.02b	0.00b	0.02b	0.01a	0.01a	0.17b
Nat. + Peat	0.10b	0.01a	0.01b	0.01b	0.03b	0.01b	0.03b	0.00b	0.01b	0.00a	0.01a	0.22b
Art. + Peat	0.47a	0.03a	0.07a	0.06a	0.75a	0.31a	0.74a	0.26a	0.32a	0.16a	0.11a	3.29a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-74 Influence of root zone media on phosphorus leaching as a function of time after planting field study II 2002 maintenance.

Root zone	Days after planting											
	97	104	111	118	132	139	153	160	166	173	180	Total
	g m^{-2}											
Uncoated	0.26b†	0.01a	0.03b	0.02bc	0.10b	0.02b	0.03b	0.02b	0.02b	0.02b	0.00b	0.54b
Unc. + Peat	0.26b	0.02a	0.05ab	0.01c	0.04b	0.04b	0.08b	0.03b	0.09b	0.02b	0.01ab	0.67b
Nat. + Peat	0.56a	0.05a	0.09ab	0.04ab	0.10b	0.05b	0.11b	0.04b	0.06b	0.04b	0.02ab	1.16b
Art. + Peat	0.41ab	0.05a	0.11a	0.06a	0.23a	0.23a	0.56a	0.27a	0.33a	0.28a	0.11a	2.64a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-75 Potassium and P leached during Field Study II maintenance relative to total K and P added and soil-test† K and P prior to Field Study II maintenance.

	K	P
	-------%--------	
Uncoated sand	57a‡	16c
Uncoated sand with peat	8a	27b
Naturally-coated sand with peat	10a	53a
Artificially-coated sand with peat	59a	3d

† Soil-test K and P are based on 30 cm root zone.

‡ Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-76 Influence of root zone media on K uptake as a function of time after planting field study II 2002 maintenance.

Root zone	Days after planting												
	97	104	111	118	125	132	139	146	153	160	166	173	180
	mg m^{-2}												
Uncoated	358.3c†	399.7b	224.7b	204.7b	146.1c	121.3bc	92.7b	170.3b	129.5ab	157.8b	58.5bc	68.6b	36.0b
Unc. + Peat	440.9ab	472.9a	294.4a	241.1ab	179.1b	159.3ab	95.8b	197.5b	108.4b	160.6ab	68.4ab	76.8ab	53.1a
Nat. + Peat	389.0bc	295.5c	216.7b	181.7b	132.5c	103.0c	68.4b	155.5b	70.3c	98.0c	39.9c	57.5b	38.3b
Art. + Peat	445.7a	443.0ab	323.2a	292.4a	220.1a	191.0a	145.2a	257.5a	157.1a	197.8a	84.0a	122.8a	58.4a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-77 Influence of root zone media on P uptake as a function of time after planting field study II 2002 maintenance.

Root zone	Days after planting												
	97	104	111	118	125	132	139	146	153	160	166	173	180
	mg m^{-2}												
Uncoated	116.2b†	122.5b	72.2b	68.0bc	49.2c	37.1b	31.1b	53.0b	43.4ab	55.9b	20.8bc	20.6b	12.5c
Unc. + Peat	137.0a	145.3a	89.8a	81.7ab	59.5b	49.4a	32.6b	59.7ab	37.6bc	60.1b	25.5b	25.0ab	17.3b
Nat. + Peat	124.4ab	95.7c	69.7b	63.9c	45.7c	33.5b	25.5b	51.5b	26.0c	39.8c	16.2c	18.9b	13.5c
Art. + Peat	142.3a	131.7ab	95.4a	93.0a	71.4a	61.0a	49.9a	83.0a	54.2a	75.7a	32.2a	40.7a	20.9a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-78 Influence of root zone media on total K and P uptake upon completion of field study II 2002 maintenance 180 DAP.

Root zone	Potassium	Phosphorus
	--------- $g\ m^{-2}$ -----------	
Uncoated	2.1c†	0.8c
Uncoated with Peat	2.4b	0.9b
Naturally with Peat	1.8d	0.7d
Artificially with Peat	2.8a	1.1a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-79 Potassium and P uptake during Field Study II maintenance relative to total K and P added and soil-test† K and P prior to Field Study II maintenance.

	K	P
	------- % --------	
Uncoated sand	117a‡	24b
Uncoated sand with peat	117a	37a
Naturally-coated sand with peat	85ab	31a
Artificially-coated sand with peat	51b	1c

† Soil-test K and P are based on 30 cm root zone.

‡ Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-80 Influence of root zone media on soil moisture content as a function of time after planting field study II.

Root zone	Days after planting†	
	140	182
	-- L L^{-1} --	
Uncoated	0.08c‡	0.11c
Uncoated with peat	0.11b	0.14b
Naturally-coated with peat	0.11b	0.15b
Artificially-coated with peat	0.14a	0.18a

†Irrigation was applied once daily.

‡Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-81 Selected properties of root zone media used in field study II upon completion December 2002.

Root zone	pH	CEC	Pa	Pw	K	Ca	Mg
		$cmol_c\ kg^{-1}$	- - - - - - - - - -	mg L^{-1}	- - - - - - - -		
Uncoated sand	7.6a†	0.1d	6.8b	2.2b	4.8b	66.0c	4.6b
Uncoated sand with peat	7.0b	5.7b	4.4b	1.5b	4.6b	121.4ab	5.2b
Naturally-coated sand with peat	6.5c	4.8c	4.1b	1.5b	5.0b	168.9ab	10.5a
Artificially-coated sand with peat	5.5d	6.4a	254.4a	10.5a	8.7a	228.3a	8.1ab

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-82 Physical properties of root-zone media in undisturbed cores upon completion of field study II.

Root-zone	K_{sat}	θ_V	φ_{BD}
	- -cm h^{-1}- -	- L L^{-1}-	g cm^{-3}
Uncoated	243.9a†	12.2c	1.71a
Uncoated with peat	196.4b	16.4b	1.59b
Naturally with peat	149.5c	19.2a	1.53c
Artificially with peat	142.6c	19.2a	1.51c

†Any means followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-83 Influence of root zone media on Rb leaching as a function of time after application field study II 2002.

Root zone	Days after application							
	0	7	14	21	28	35	42	Total
	- - - - - - - - - - - - - - - - mg m^{-2} - - - - - - - - - - - - - - - -							
Uncoated	0.0a†	50.3a	15.2a	69.0a	24.3a	9.3a	0.3a	168.5a
Unc. + Peat	0.0a	0.0b	0.6b	21.4a	9.4b	4.2a	0.1ab	35.6b
Nat. + Peat	0.0a	0.0b	0.0b	8.5b	6.1b	4.5a	0.3a	19.5b
Art. + Peat	0.0a	0.0b	0.2b	0.0b	0.0c	0.0b	0.0b	0.2c

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table 4-84 Influence of root zone materials on soil rubidium.

Root zone	Soil Rb^{1+}
	- - mg 10 cm^{-1} - -
Uncoated sand	43.75b
Uncoated sand with peat	37.50b
Naturally-coated sand with peat	31.25b
Artificially-coated sand with peat	81.25a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

CHAPTER 5

CONCLUSIONS

The influence of peat and coated sands on root zone properties, and on turfgrass response, were studied in both the glasshouse and in the field. Sand coatings of clay, regardless of the source or method of coating, imparted a number of similar properties to the root zone mixes.

Artificially-coated sand and peat positively influenced water relations in simulated sand-based putting greens and under field conditions. It was observed, using laboratory techniques, that artificially-coated sand improved moisture content at high negative pressures, thereby increasing available water to turf which, in the absence of coatings and peat, can encounter a water deficit. The presence of natural and artificial coatings increased water use efficiency two and three years following establishment. Moreover, as detected by soil moisture sensors, the presence of coated sands and peat increased root zone moisture content under field conditions. On the other hand, the important putting green physical property of adequate saturated hydraulic conductivity (K_{sat}) was not negatively reduced by the use of coated sands.

Cation exchange capacity of root zone mixes was increased by the presence of sand grain coatings and peat. In both glasshouse and field studies root zones mixtures consisting of naturally- and artificially-coated sands had greater CEC than uncoated sand.

In the field, however, the CEC of naturally-coated sand decreased with time perhaps as easily detachable sand grain coatings elluviated with percolate water. The CEC of artificially-coated sands used in both glasshouse and field studies changed little with time indicating a measure of coating stability. While the CEC of uncoated sand alone did not increase with time, the CEC of uncoated sand root zones were increased substantially by peat as determined three years after planting in the glasshouse studies and during two field studies lasting approximately one year each.

The benefits of naturally-coated sand and peat on bermudagrass coverage during establishment differed between glasshouse and field studies. While presence of a highly coated, naturally-coated sand increased bermudagrass coverage in the glasshouse, no increase in bermudagrass coverage relative to uncoated sand was observed using naturally-coated sand in the field study. The inclusion of peat did not increase bermudagrass coverage in the glasshouse, in the field, however, uncoated sand amended with peat increased bermudagrass coverage relative to uncoated sand alone probably by increasing root zone moisture content.

Inclusion of artificially-coated sand consistently increased bermudagrass coverage relative to uncoated sand during establishment in both the glasshouse and field studies. Moreover, incorporation rates up to a maximum of 33% artificially-coated sand on a volume basis increased bermudagrass coverage during establishment in uncoated sand root zone with and without peat.

Sand grain coatings increased clipping production, decreased the quantity of P and K leached, and increased soil-test P and K relative to uncoated sand. Glasshouse findings

suggest that a coated sand consisting of phyllosilicate clays and Fe and Al oxides increased clipping production, decreased P and K leached, and increased soil-test P and K relative to uncoated sand. The ability of naturally-coated sand to increase clipping production, decrease the quantity of P and K leached, and increase soil-test P and K may severely be diminished by the mining and sizing processes. Furthermore, detachment of phyllosilicate clay may increase P and K leached from naturally-coated sand. Artificially-coated sands, however, which are not subject to post-mining processes, consistently increased 'Tifdwarf' bermudagrass clipping production. While relative P and K leached can be decreased in the presence of artificially-coated sands, the ability of artificially-coated sands to reduce P and K loss can be masked because of inherent soluble P and K associated with the artificial-coatings. Findings in the glasshouse with K and in the field with Rb suggest that artificial-sand grain coatings can decrease the loss of cations from a sand based root zone mixture.

The inclusion of a highly-coated naturally- and artificially-coated sand can increase P and K uptake relative to uncoated sand. In the glasshouse naturally-coated sand increased the quantity of P and K uptake relative to uncoated sand. Increased P uptake from naturally-coated sand in which the coatings consist of Fe and Al oxides is not likely due to decreased P availability of chemisorbed P since it was observed that 'Tifdwarf' tissue P concentrations decreased in the presence of the Fe and Al containing naturally-coated sand. In the field, however, naturally-coated sand did not increase P and K uptake relative to uncoated sand probably because of coating detachment resulting from the mining and sizing process. The inclusion of artificially-coated sand increased P

and K uptake relative to uncoated sand in both glasshouse and field studies.

Peat improved many properties of uncoated sand. The addition of peat to uncoated sand increased CEC, water holding capacity, and number of days until wilt of the mix. Relative to uncoated sand alone, when uncoated sand is amended with peat, coverage and clipping production, were increased. The presence of peat, however, did not increase nutrient retention or soil fertility, therefore, the greatest benefit of peat lies in its ability to retain moisture.

Thus, both in the glasshouse and in the field, the sands which were artificially-coated with Ca-montmorillonite clay increased turfgrass coverage during establishment, the clipping production, water holding capacity, and CEC. Peat also positively influenced these characteristics in all studies. However, naturally-coated sand only increased coverage and P retention in the glasshouse, and the water holding capacity in the field.

The use of coated sands and peat improved many poor characteristics of sand-based putting green root zones without negatively influencing root zone performance. When availability and consistency allow, a naturally-coated sand, with phyllosilicate clay and Fe and Al oxide coatings, should be used in sand based putting green root zones in order to reduce potential P leaching to P sensitive environments. During establishment, when coverage and moisture retention are of concern, the incorporation of peat should be considered as an amendment to sand-based putting green root zones. Finally, an artificially-coated sand amendment to sand-based putting greens both with and without peat should be considered when bermudagrass coverage, moisture retention, nutrient retention, and overall fertility are of concern during establishment and maintenance.

APPENDIX A
GLASSHOUSE AND FIELD STUDY DATA TABLES

Table A-1 Influence of peat and coating main effects on tissue K concentration by bermudagrass as a function of time after planting phase I 2000.

Main effects	Days after planting			
	29	43	58	71
	- - - - - - - - - - - - - - % - - - - - - - - - - - - - - - -			
Peat				
With	1.09a†	3.14a	1.16a	2.04a
Without	0.99a	2.34b	1.00a	1.84a
Sand coating				
Uncoated	0.50b	1.02b	0.67b	1.60b
Naturally	1.21a	1.38a	1.34a	2.11a
Artificially	1.42a	1.56a	1.23a	2.10a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-2 Influence of peat and coating main effects on tissue P concentration by bermudagrass as a function of time after planting phase I 2000.

Main effects	Days after planting			
	29	43	58	71
	- - - - - - - - - - - - - - % - - - - - - - - - - - - - - - -			
Peat				
With	0.40a†	0.36a	0.32a	0.40a
Without	0.39a	0.30b	0.32a	0.34a
Sand coating				
Uncoated	0.25b	0.32b	0.29b	0.36ab
Naturally	0.32b	0.23c	0.28b	0.32b
Artificially	0.60a	0.45a	0.40a	0.43a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-3 Influence of peat and coating main effects on tissue K concentration by bermudagrass as a function of time after planting phase II 2001.

Main effects	Days after planting			
	355	370	381	397
	--------------%--------------			
Peat				
With	1.85a†	1.88a	1.87a	1.94a
Without	1.80a	1.82a	1.78a	1.82a
Sand coating				
Uncoated	1.60b	1.71b	1.74b	1.66c
Naturally	1.87a	1.87ab	1.75b	1.90b
Artificially	2.02a	1.97a	1.99a	2.08a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-4 Influence of peat and coating main effects on tissue P concentration by bermudagrass as a function of time after planting phase II 2001.

Main effects	Days after planting			
	355	370	381	397
	--------------%--------------			
Peat				
With	0.60a†	0.55a	0.53a	0.56a
Without	0.60a	0.57a	0.50a	0.56a
Sand coating				
Uncoated	0.62b	0.57b	0.55a	0.55b
Naturally	0.46c	0.46c	0.40b	0.48c
Artificially	0.72a	0.66a	0.58a	0.63a

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-5 Influence of peat and coating main effects on tissue K concentration by bermudagrass as a function of time after planting phase III 2002.

Main effects	Days after planting			
	699	715	729	746
	- - - - - - - - - - - - - - % - - - - - - - - - - - - - - - -			
Peat				
With	1.19a†	1.62a	1.92a	1.57‡
Without	1.13a	1.48b	1.80a	1.70
Sand coating				
Uncoated	1.12a	1.44a	1.89a	1.52
Naturally	1.22a	1.61a	1.88a	1.68
Artificially	1.15a	1.60a	1.82a	1.70

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

‡Comparisons among main effects (Peat and Sand Coating) are not made due to interactions between main effects.

Table A-6 Interaction of coating and peat on tissue K concentration by bermudagrass phase III 2002.

Coating	Peat	Days after planting
		746
		- % -
Uncoated	with	1.38
Uncoated	without	1.66
Naturally-coated	with	1.74
Naturally-coated	without	1.62
Artificially-coated	with	1.58
Artificially-coated	without	1.81
$LSD_{0.05}$		2.26
Significance of the Peat X Coating interaction		0.03

Table A-7 Influence of peat and coating main effects on tissue P concentration by bermudagrass as a function of time after planting phase III 2002.

Main effects	Days after planting			
	699	715	729	746
	- - - - - - - - - - - - - % - - - - - - - - - - - - - - -			
Peat				
With	0.24a†	0.32a	0.39a	0.36‡
Without	0.25a	0.31a	0.38a	0.39
Sand coating				
Uncoated	0.27a	0.31a	0.40a	0.37
Naturally	0.22b	0.32a	0.36a	0.37
Artificially	0.24ab	0.32a	0.39a	0.39

†Any means within the same column and main effects (Peat and Sand Coating) followed by the same letter are not different ($P > 0.05$) by Duncan's Multiple Range Test.

‡Comparisons among main effects (Peat and Sand Coating) are not made due to interactions between main effects.

Table A-8 Interaction of coating and peat on tissue P concentration by bermudagrass phase III 2002.

Coating	Peat	Days after planting
		746
		- % -
Uncoated	with	0.32
Uncoated	without	0.42
Naturally-coated	with	0.38
Naturally-coated	without	0.36
Artificially-coated	with	0.37
Artificially-coated	without	0.40
$LSD_{0.05}$		0.04
Significance of the Peat X Coating interaction		0.00

Table A-9 Influence of root zone media on potassium leaching concentration as a function of time after planting (0 - 63 DAP) establishment field study I 2001 -2002.

Root zone	Days after planting												
	2	5	10	15	20	23	28	32	39	42	45	51	63
	mg L^{-1}												
Uncoated	15.13b†	2.18b	4.32b	9.25b	14.68b	10.00b	19.50b	30.75b	66.50b	20.25b	46.67a	23.33b	38.75b
Unc. + Peat	10.18b	0.88b	1.30b	8.28b	11.88b	15.00b	21.00b	20.25b	37.75b	12.75b	33.75a	12.75b	34.50b
Nat. + Peat	4.55b	5.80b	2.18b	3.28b	7.60b	10.00b	15.75b	20.50b	62.25b	13.00b	37.00b	15.50b	49.50b
Art. + Peat	240.50a	104.62a	114.68a	212.50a	206.00a	145.00a	140.25a	118.00a	181.00a	70.00a	112.00a	47.50a	120.00a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-10 Influence of root zone media on potassium leaching concentration as a function of time after planting (71 - 90 DAP) establishment field study I 2001 -2002.

Root zone	Days after planting			
	71	75	81	90
	mg L^{-1}			
Uncoated	25.00ab†	21.00a	31.33a	24.50a
Unc. + Peat	13.00b	18.50a	28.25a	24.25a
Nat. + Peat	26.75ab	33.75a	37.75a	34.75a
Art. + Peat	48.25a	32.25a	71.75a	47.25a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-11 Influence of root zone media on phosphorus leaching concentration as a function of time after planting (0 - 63 DAP) establishment field study I 2001 -2002.

Root zone	Days after planting												
	2	5	10	15	20	23	28	32	39	42	45	51	63
	mg L^{-1}												
Uncoated	0.08b†	0.08c	0.38c	1.00b	0.62b	0.90b	4.00ab	18.78a	5.75a	8.05ab	3.30a	7.60ab	3.82a
Unc. + Peat	0.38b	1.45b	0.88bc	0.50b	0.38b	0.65b	2.20b	4.20bc	3.40ab	5.05ab	1.40a	7.02ab	5.82a
Nat. + Peat	3.68a	2.32ab	2.68a	2.55a	3.72a	3.52a	6.15a	5.85b	6.40ab	10.32a	6.25a	10.00a	11.32a
Art. + Peat	3.62a	2.68a	2.10ab	1.35b	1.20a	1.40a	1.28b	1.85c	3.08a	3.02a	2.28a	3.25b	3.78a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-12 Influence of root zone media on phosphorus leaching concentration as a function of time after planting (71 - 90 DAP) establishment field study I 2001 -2002.

Root zone	Days after planting			
	71	75	81	90
	mg L^{-1}			
Uncoated	7.23a†	8.17a	14.07a	7.75ab
Unc. + Peat	2.10a	3.62a	4.65a	8.30ab
Nat. + Peat	7.28a	9.18a	12.32a	16.98a
Art. + Peat	2.85a	3.22a	4.25a	6.08b

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-13 Influence of root zone media on tissue K concentrations as a function of time after planting field study I.

Root zone	Days after planting					
	38	50	57	74	81	88
	------------ % ------------					
Uncoated	0.50b†	0.70b	1.05b	1.35a	1.20b	1.58ab
Unc. + Peat	1.25a	1.10ab	1.30a	1.45a	1.45a	1.72a
Nat. + Peat	0.89ab	0.90ab	1.32a	1.68a	1.42ab	1.52ab
Art. + Peat	1.16a	1.12a	1.28a	1.60a	1.58a	1.30b

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-14 Influence of root zone media on tissue P concentrations as a function of time after planting field study I.

Root zone	Days after planting					
	38	50	57	74	81	88
	------------ % ------------					
Uncoated	0.18a†	0.29a	0.33b	0.46a	0.40b	0.50a
Unc. + Peat	0.31a	0.36a	0.39a	0.46a	0.47ab	0.50a
Nat. + Peat	0.25a	0.30a	0.40a	0.54a	0.48ab	0.46ab
Art. + Peat	0.29a	0.36a	0.40a	0.50a	0.49a	0.39b

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-15 Influence of root zone media on percolate potassium concentration as a function of time after planting maintenance field study I 2001 -2002.

Root zone	Days after planting							
	99	118	125	130	140	154	167	199
	----------------- mg L^{-1} -----------------							
Uncoated	26.3a†	22.3b	4.0b	2.0c	4.0b	4.2b	4.0b	2.8b
Unc. + Peat	30.3a	28.0ab	18.8ab	6.8c	5.0b	3.0b	1.2b	1.0b
Nat. + Peat	35.5a	28.8ab	33.2a	20.5b	11.5b	4.2b	2.0b	0.2b
Art. + Peat	44.2a	37.8a	20.8ab	48.5a	38.2a	38.5a	30.2a	14.2a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-16 Influence of root zone media on percolate phosphorus concentration as a function of time after planting maintenance field study I 2001 -2002.

Root zone	Days after planting							
	99	118	125	130	140	154	167	199
	----------------- mg L^{-1} -----------------							
Uncoated	5.5a†	5.2a	2.0b	4.5a	1.5c	1.0b	0.6c	0.6b
Unc. + Peat	14.3a	7.7a	6.0ab	6.1a	6.8a	3.0a	1.2bc	0.4b
Nat. + Peat	16.0a	10.7a	9.6a	6.5a	7.7a	3.4a	3.3a	1.3a
Art. + Peat	11.3a	6.9a	5.1ab	4.6a	4.0b	2.4a	1.6a	0.6b

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-17 Influence of root zone media on tissue K concentration as a function of time after planting field study I maintenance.

Root zone	Days after planting					
	130	143	157	187	200	214
	------------- g m^{-2} -------------					
Uncoated	1.34bc†	1.24b	1.78b	1.35b	1.36b	1.30a
Unc. + Peat	1.61ab	1.51a	1.90ab	1.44ab	1.30b	1.51a
Nat. + Peat	1.24c	1.32ab	1.75b	1.44ab	1.26b	1.36a
Art. + Peat	1.65a	1.51a	2.02a	1.69a	1.58a	1.62a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-18 Influence of root zone media on tissue P concentration as a function of time after planting field study I maintenance.

Root zone	Days after planting					
	130	143	157	187	200	214
	------------- g m^{-2} -------------					
Uncoated	0.36b†	0.32b	0.48c	0.32a	0.36c	0.35b
Unc. + Peat	0.46a	0.38a	0.55ab	0.37a	0.38bc	0.40ab
Nat. + Peat	0.33b	0.34ab	0.52b	0.39a	0.41ab	0.43a
Art. + Peat	0.41ab	0.37ab	0.57a	0.40a	0.43a	0.42a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-19 Influence of root zone media on potassium leachate concentration as a function of time after planting field study II 2002.

Root zone	Days after planting													
	3	7	12	18	29	34	40	47	55	62	69	76	83	90
	mg L^{-1}													
Uncoated	15.75b†	12.00b	9.75b	8.00b	3.50b	2.10c	2.12b	2.00b	5.22ab	5.22ab	6.60b	11.18a	4.28b	14.85a
Unc. + Peat	6.00c	7.50bc	6.00bc	9.50b	10.75b	6.60b	3.15b	2.52b	4.95ab	4.95ab	1.38c	2.65b	3.75b	2.70c
Nat. + Peat	4.25c	4.50b	3.50c	5.50b	6.50b	3.98bc	2.45b	1.90b	3.85b	3.85b	1.38c	1.65b	1.78b	1.95c
Art. + Peat	23.75a	26.00a	21.25a	26.25a	29.25a	19.30a	13.85a	9.92a	13.75a	13.75a	13.48a	15.82a	13.55a	9.58b

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-20 Influence of root zone media on phosphorus leachate concentration as a function of time after planting field study II 2002.

Root zone	Days after planting													
	3	7	12	18	29	34	40	47	55	62	69	76	83	90
	mg L^{-1}													
Uncoated	4.10a†	0.46a	3.25a	2.85a	1.38b	1.48b	1.50b	1.48b	0.30b	2.68a	2.02a	2.54a	3.88a	6.65a
Unc. + Peat	1.50bc	0.21a	1.80a	1.75a	2.30ab	2.45ab	2.50a	2.88a	0.32b	0.82a	0.90a	0.66b	2.56a	2.42b
Nat. + Peat	3.50ab	0.39a	3.22a	3.10a	3.08a	3.00a	3.05a	3.08a	1.22ab	2.12a	1.88a	1.28ab	2.31a	4.44ab
Art. + Peat	1.18c	0.28a	3.25a	1.80a	3.00a	2.90a	3.10a	3.15a	1.82a	2.02a	1.68a	1.16aa	3.51a	3.02b

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-21 Influence of root zone media on tissue K concentration as a function of time after planting field study II 2002.

Root zone	Days after planting									
	28	34	41	47	55	62	69	76	83	90
	%									
Uncoated	0.32c†	0.37c	0.43c	0.88b	0.95a	1.25a	1.12b	1.20a	1.62a	1.65b
Unc. + Peat	0.50b	1.04b	0.94b	1.35a	1.05a	1.28a	1.55ab	1.48a	1.85a	1.82ab
Nat. + Peat	0.52b	1.44a	0.96b	1.25a	0.95a	1.22a	1.35ab	1.35a	1.68a	1.82ab
Art. + Peat	1.10a	1.52a	1.46a	1.40a	1.30a	1.65a	1.65a	1.55a	1.82a	1.98a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-22 Influence of root zone media on tissue P concentration as a function of time after planting field study II 2002.

Root zone	Days after planting									
	28	34	41	47	55	62	69	76	83	90
	%									
Uncoated	0.19c†	0.14c	0.21c	0.33b	0.40a	0.44a	0.37a	0.43a	0.51a	0.48b
Unc. + Peat	0.25b	0.34b	0.35b	0.52a	0.42a	0.41a	0.50a	0.50a	0.58a	0.56a
Nat. + Peat	0.26b	0.40ab	0.34b	0.49a	0.40a	0.42a	0.47a	0.49a	0.57a	0.54ab
Art. + Peat	0.34a	0.42a	0.44a	0.48a	0.43a	0.51a	0.50a	0.51a	0.56a	0.58a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-23 Influence of root zone media on potassium leachate concentration as a function of time after planting field study II 2002 maintenance.

Root zone	Days after planting										
	97	104	111	118	132	139	153	160	166	173	180
	g m^{-2}										
Uncoated	2.55b†	2.00b	1.90b	1.92b	3.58b	2.82ab	3.18ab	5.88a	2.90a	3.08a	3.08a
Unc. + Peat	1.78b	1.00b	1.38b	0.85b	0.45b	0.20b	0.35b	0.12b	0.28a	0.28a	0.50a
Nat. + Peat	1.68b	1.55b	1.32b	1.45b	0.65b	0.35b	0.42b	0.20b	0.30a	0.25a	0.38a
Art. + Peat	7.50a	5.75a	5.40a	6.28a	10.68a	6.62a	6.78a	4.58ab	4.45a	3.08a	3.45a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-24 Influence of root zone media on phosphorus leachate concentration as a function of time after planting field study II 2002 maintenance.

Root zone	Days after planting										
	97	104	111	118	132	139	153	160	166	173	180
	g m^{-2}										
Uncoated	4.42b†	4.40b	3.18c	3.18b	1.68ab	0.78b	0.42c	0.82b	0.36b	0.54b	0.20b
Unc. + Peat	6.10b	5.70ab	6.10b	4.55ab	1.12b	1.48b	1.55b	1.15b	1.30b	0.80b	0.44b
Nat. + Peat	9.74a	8.88a	9.10a	7.10a	1.60ab	1.45b	1.52b	1.25b	1.11b	1.23b	0.60b
Art. + Peat	6.50ab	8.32a	8.38ab	7.05a	2.90a	4.78a	5.12a	5.40a	4.46a	5.80a	2.98a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-25. Influence of root zone media on tissue K concentration as a function of time after planting field study II 2002 maintenance.

Root zone	Days after planting												
	97	104	111	118	125	132	139	146	153	160	166	173	180
	g m^{-2}												
Uncoated	1.60a†	1.48a	1.28b	1.10b	1.15ab	1.18a	1.06b	1.18a	1.19ab	1.24a	0.98a	1.02a	0.90a
Unc. + Peat	1.62a	1.60a	1.48ab	1.12ab	1.18ab	1.28a	0.98b	1.29a	1.00b	1.19a	0.95a	0.92a	1.10a
Nat. + Peat	1.72a	1.35a	1.38b	1.15a	1.05b	1.15a	0.98b	1.30a	1.02b	1.14a	0.82a	0.95a	0.95a
Art. + Peat	1.68a	1.55a	1.60a	1.35a	1.32a	1.32a	1.26a	1.35a	1.27a	1.29a	1.03a	1.22a	1.00a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

Table A-26. Influence of root zone media on tissue P concentration as a function of time after planting field study II 2002 maintenance.

Root zone	Days after planting												
	97	104	111	118	125	132	139	146	153	160	166	173	180
	g m^{-2}												
Uncoated	0.52a†	0.45a	0.41a	0.37b	0.39ab	0.35a	0.35a	0.36a	0.40ab	0.44a	0.35ab	0.31a	0.31a
Unc. + Peat	0.50a	0.49a	0.45a	0.38b	0.39ab	0.39a	0.34b	0.39a	0.34b	0.45a	0.35ab	0.30a	0.36a
Nat. + Peat	0.55a	0.44a	0.44a	0.40ab	0.37b	0.37a	0.36b	0.43a	0.38ab	0.46a	0.33b	0.31a	0.34a
Art. + Peat	0.54a	0.46a	0.47a	0.43a	0.43a	0.42a	0.43a	0.43a	0.44a	0.49a	0.39a	0.40a	0.35a

†Any means within the same column followed by the same letter are not statistically different ($P > 0.05$) by Duncan's Multiple Range Test.

APPENDIX B
GLASSHOUSE AND FIELD STUDY XRD GRAPHS

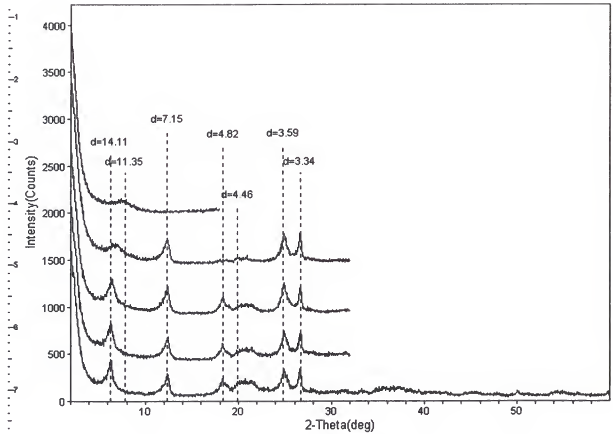

Fig. B-1 X-ray diffraction graph of sand grain coatings removed from naturally-coated sand used in glasshouse study.

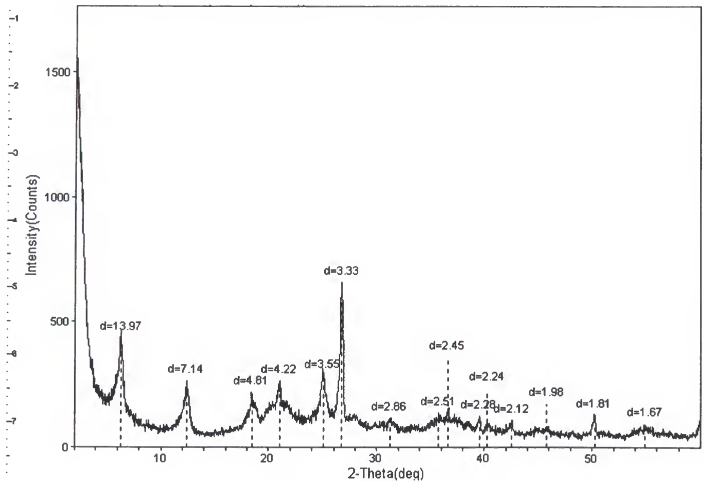

Fig B-2. X-ray diffraction graphs of sand grain coatings removed from naturally-coated sand following use in glasshouse studies Phase I - III.

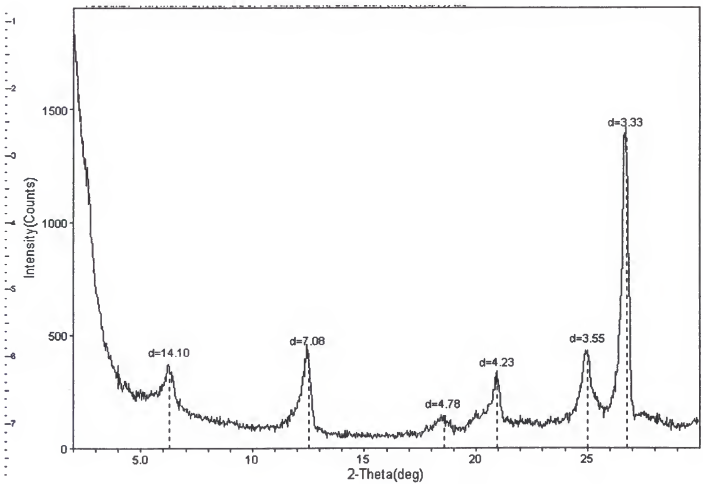

Fig B-3. X-ray diffraction of sand grain coatings removed from naturally-coated sand used in Field Studies.

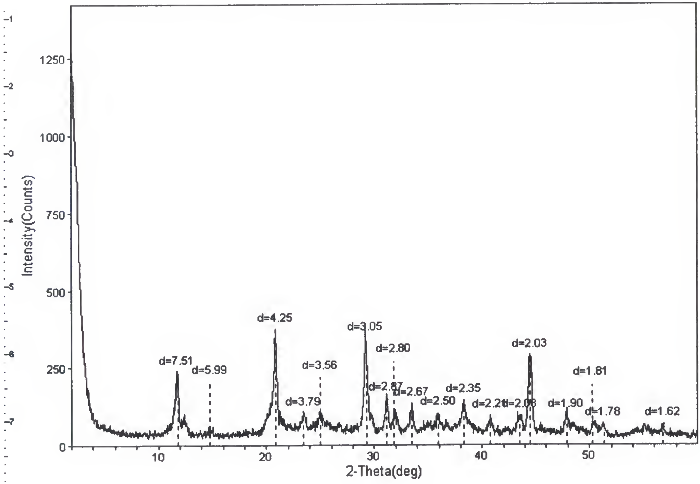

Fig B-4. X-ray diffraction graph of material found in percolate water of naturally-coated sand with peat treatment used in Field Studies.

APPENDIX C
FIELD STUDY II FIGURES

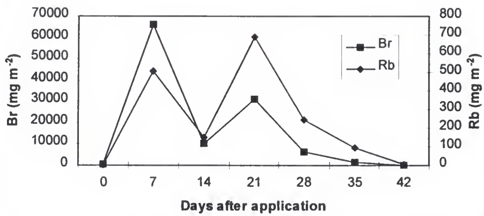

Fig C-1 Bromide and rubidium leaching in an uncoated sand root zone.

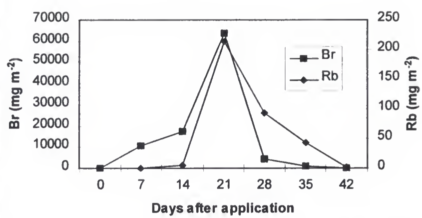

Fig C-2 Bromide and rubidium leaching in an uncoated sand with peat root zone

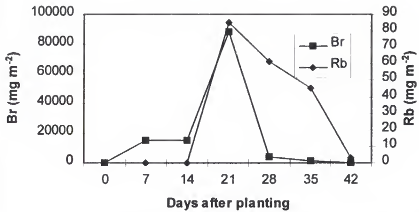

Fig C-3 Bromide and rubidium leaching in a naturally-coated sand with peat root zone.

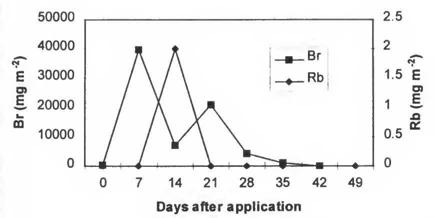

Fig C-4 Bromide and rubidium leaching in an artificially-coated sand with peat root zone.

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BIOGRAPHICAL SKETCH

Raymond Heft Snyder was born on 10 July 1973 in Boynton Beach, FL. He attended John I. Leonard High School in Lake Worth, FL, and graduated in 1991. Following graduation he spent two years at Palm Beach Community College where he graduated with an associate's degree in business administration in the fall of 1993. He enrolled at the University of Florida in the spring of 1994 were he began work on his bachelor's degree in agriculture operations management. During the next two years, he would develop a great interest in turfgrass management and soil science. Following graduation in the spring of 1996, he began pursuit of his master's degree in soil and water science under the tutelage of Dr. Jerry B. Sartain. Raymond completed his master's degree program in December of 1998 and remained at the University of Florida to pursue a doctoral degree in soil and water science under the continued tutelage of Dr. Jerry B. Sartain. The rest is yet to be told.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the College of Agriculture and Life Sciences and to the Graduate School and was acceptable as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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